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Maximum Realisable Technical Potentials in the Dutch Municipalities Utrecht & De Bilt

Achieving Energy-Neutrality by 2030

M. Sc. Thesis – Sustainable Development: Energy & Resources

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1 SUMMARY

The Dutch municipalities of Utrecht and De Bilt have communicated the ambitious goal of achieving domestic energy-neutrality by 2030. The main goal of this research has been to determine the maximum realisable technical potentials in terms of energy-efficiency improvements and renewable energy production options within the municipal borders. A reference scenario for 2030 has been set-up based on the Dutch 'Nationale Energieverkenning' and a Maximum Realisable Technical Potential scenario has been constructed based on a literature review.

For the municipality of Utrecht, a maximum realisable technical potential relating to energy efficiency options is framed at a domestic primary energy demand of 9,659 TJp by 2030. When compared to the reference scenario this causes a reduction of primary energy demand of 9,330 TJp with an associated 313,759 Tonne of avoided CO_{2eq} emissions. An additional 1,911 TJ of renewable energy is produced when compared to the reference scenario and an associated additional 154,243 Tonne of CO_{2eq} has been abated. As a consequence the municipality of Utrecht could produce roughly a quarter of its projected domestic primary energy requirements; a large increase but not enough to achieve energy-neutrality. The total associated costs amount to 4,492 Million euro with respect to the projected energy-efficiency measures and 668 Million associated with renewable energy production options.

For De Bilt, the maximum realisable technical potential relating to energy efficiency options is framed at a domestic primary energy demand of 2,201 TJp by 2030 with an associated 46,224 Tonne of additionally avoided CO_{2eq} emissions. An additional 5,673 TJ of renewable energy is produced when compared to this reference scenario and 508,826 Tonne of CO_{2eq} has been abated. De Bilt has the potential to produce roughly three times its own projected domestic primary energy requirement by 2030. The total associated costs amount to 879 million for the energy-efficiency options and 1,747 million for the renewable energy production options.

It is deemed imperative that both the energy-efficiency options and the identified renewable energy options are implemented in unison and it is explicitly mentioned that, due to the complex nature and interactions related to such an analysis, the results should be viewed as indicative of general developments and requirements related to the municipal energy-systems. In-depth future studies are required in order to give a more robust and holistic picture of achieving municipal energy-neutrality by 2030.

2 INTRODUCTION

Average global temperature increase due to anthropogenic greenhouse gas (GHG) emissions should not exceed 2°C above pre-industrial times (UNFCCC, 2009). As a direct requirement, cumulative GHG emissions need to be cut back throughout the twenty-first century (Meinshausen et al., 2009). This objective has been recognized by the European Council, triggering debate on which conjoined strategies should best serve these interests(European Parliament, 1993). Reflecting discrepancies between Member States (European Commission, 2012a), legally binding national targets and renewable energy action plans were established, requiring higher GHG emission reductions of wealthier Member States and limited increases for those with less investment capacity (Commission of the European Communities, 2008).

However, though the environmental benefits of such actions seem undisputed, the required future developments of economic costs, technologies and both political and behavioural aspects underlying and justifying these strategies continues to be a much debated issue (Lehr et al., 2008; Faber et al., 2012). What seems clear is that in order to take meaningful action, Member States should converge national, regional and local sustainable development initiatives and facilitate streamlined cooperation as a prerequisite of smooth operation (European Parliament, 2009).

In relation to this, Dutch municipalities, provinces and water boards produced a broad 'Duurzaamheidsagenda', in conjunction with the national government, which plays a crucial part in the realization of said established national and overarching European goals. Herein, local and regional authorities are encouraged to actively achieve reductions of GHG emissions through sustainable development and are even stimulated to set still more ambitious targets and corresponding action plans (Ministerie van Infrastructuur en Milieu, 2011; European Parliament, 2009b).

Through the local energy-cooperatives BENG! and Energie-U, the Dutch neighbouring municipalities De Bilt and Utrecht have communicated precisely such an ambitious goal: Achieving domestic energy-neutrality by 2030. In addition to the overall environmental benefits (both local and global), establishing energy-neutrality by 2030 could potentially yield a number of accompanying beneficial effects for Utrecht and De Bilt. Progress towards a secure energy system (i.e. non-depend on an increasingly vulnerable energy supply system) and successful implementation of sustainable energy-related technologies is expected; whilst sustainable public and private local initiatives potentially generate new opportunities for jobs and growth (European Parliament, 2009b; European Commission, 2012b; Gemeente De Bilt, 2009b; European Parliament, 2012; Buck et al., 2010).

However, concrete long-term (i.e. post 2020) strategies are found lacking (Benner & Warringa 2012; Verkruijssen et al. 2014). Having fortified indicative sustainable development frameworks, specifically focussing on energy efficiency improvements and sustainable energy production, both municipalities have expressed a need for concrete and robust measures (Gemeente De Bilt, 2009b; Oude Lohuis et al., 2015). Due to this identified discrepancy between the indicative 2030 ambitions (consisting of more long term targets) and the present policy packages, the need to translate these ambitions into *actual binding policies* in order to have a clear and demonstrable impact has been inculcated.

According to the municipalities' wishes, taking action initially revolves around identifying the required realisable technical options and their associated costs. This shall be determined through analysis of the current energy-systems, linked with projected technological and investment options related to the projected energy demand and limited to the generation and usage of (transport)fuels, electricity and heat.

While numerous independent studies exploring (parts of) future energy-systems exist, these often have a specific focus. De Wit and Faaij (2010), for instance, estimated the European biomass resource potential and costs up to 2030, Van Vliet et al. (2011) analysed the potential energy use, cost and CO2 emissions of European electric cars in 2030. With respect to the Netherlands, a more limited amount of scientific studies is available. These mostly relate to either techno-economic potentials for CCS (van den Broek et al., 2010; Strachan et al., 2011), those of biomass (van Dam et al., 2009; de Best-Waldhober et al., 2012) or energy-efficiency measures (Harmelink et al., 2010) and therefore only provide a legitimate scientific basis on these specific subjects while leaving other areas wanting. Fortunately, Van der Ree (2014), Oude Lohuis et al. (2015) and Benner and Warringa (2012) provided indicative results regarding the current and projected developments of the municipal energy-systems of De Bilt and Utrecht which are combined with data supplied through the Dutch national energy exploration documents (M. Hekkenberg & Verdonk, 2014), the manual for monitoring municipal GHG emissions and renewable energy production (Ministerie van Infrastructuur en Milieu, 2013), the explorative renewable energy potential in the Dutch municipality of Enschede (Gerdes & van Zuijlen, 2015) and supplemented by multiple SERPEC-CC studies (e.g. Bettgenhäuser et al., 2009).

It thereby aims to supply valuable insights into the required technological developments and costs of realising municipal energy-neutrality by 2030, and aims to strengthen the scientific literature and practical implementation with respect to said goals in the field of sustainable development; specifically within local governments. Numerous options are identified and their appropriateness and viabilities are discussed. In this manner it aims to increase the understanding of the applicability of different projected developments to more regional surroundings and identified discrepancies herein are deliberated upon. Finally, it provides insights into the understanding of the direction of future studies focussing on more in-depth analysis of the effects of specific energy-efficiency and sustainable energy options. With these goals in mind, the main research question is proposed:

- *What are the maximum realisable technical potentials and associated costs of the energy-systems of De Bilt and Utrecht, aimed at achieving energy-neutrality by 2030?*

A multi-facet approach is established, focussing on energy demand reductions through improvements in energy efficiency on the on hand, and sustainably producing the remainder of said energy demand on the other. The ensuing sub-questions are proposed:

- o *What is the maximum realisable technical potential relating to energy efficiency options, applicable to local improvements in the energy systems of municipalities De Bilt and Utrecht aimed at achieving energy-neutrality by 2030, and what are the associated costs?*

- *What is the maximum realisable technical potential for locally produced renewable energy options, supplying energy to the energy systems of municipalities De Bilt and Utrecht aimed at achieving energy-neutrality by 2030 and what are the associated cost?*

Additionally, multiple studies have indicated that these goals may not be reached by the development of energy-efficiencies and domestic renewable electricity alone (Junginger et al., 2004). Adhering to this, Dutch governmental policies point out the possible necessity for import of renewable electricity to reach the targets (Ministry of Economic Affairs, 2002), through either the purchase of sustainably produced energy or through direct (partial) investment tenders such-as off-shore wind-, or PV-parks (AgentschapNL, 2013). Since a detailed analysis hereof lies outside the scope of the current research it is omitted.

In the succeeding chapter the methodology is set out, elucidating on defining relevant concepts and setting up both current and projected municipal energy-, and GHG-balances. This is followed by expanding on the methodological approach applied in order to determine the maximum realisable technical potentials for energy-efficiency and sustainable energy production. The results hereof are presented, interpreted and contrasted in the conclusion before the discussion is presented. The references and appendices as referred to throughout this document are provided followed by the acknowledgements.

3 METHODOLOGY

The achievement of domestic energy neutrality depends on numerous factors, such as the selected definition of renewable energy, the domestic energy consumption, the domestic technical potential of renewable energy and the specific support measures influencing the actual attainable part of said prospective (Junginger et al., 2004). These will be set-out first. Adjacent relevant socio-political structures are deemed outside of the current scope.

With respect to establishing the different projections for the energy-systems, firstly the respective concepts relating to Dutch municipal sustainable energy-systems and the implications hereof on the pathways to be established are defined. Energy and GHG-balances for both Utrecht and De Bilt, ranging from 2008 until the most recent data available (most often 2014), are demarcated, constructed and elucidated upon, predominantly based on the “Handboek monitoring broeikasgasemissies en hernieuwbare energie bij lokale overheden” (Ministerie van Infrastructuur en Milieu, 2013) and associated data as presented in the online database-tool KlimaatMonitor (www.klimaatmonitor.databank.nl)

Secondly, plausible expectations relating to the general development of the municipal energy systems until 2030 are provided for, primarily derived out of the Dutch ‘Nationale Energieverkenning’ (national energy-exploration documents). Herein, a general pathway is provided for where both currently established as well as intended policy measures are incorporated (known as the ‘Intended Policies’ pathway). This ‘Intended Policies’ (IP) projection encapsulates those proposed policy measures (both Dutch and European) that were deemed sufficiently concrete as of May 2014 (Michiel Hekkenberg & Verdonk, 2014a). The function hereof is elucidated upon in chapter 3.5.

Thirdly, assumptions, methods and results of multiple studies aimed at delivering projections for the maximum realisable technical potentials for (Dutch) energy-efficiency and renewable energy production options are contrasted and applied to the present-day (i.e. 2014) energy-, and GHG balances and projected until the target year of 2030. These are expanded upon in chapter 3.6 and 3.7.

All of the identified options and their associated costs are presented graphically per municipality and per constituting sectors; associated information is provided for in the appendices where stated.

3.1. DEFINITIONS AND CONCEPTS

Energy-Neutrality, GHGs, Renewable Energy, Energy Efficiency, and Type of Potential

First-off, energy-neutrality is explicitly defined as an equitable balance between the domestic energy demand and the energy produced so that the net difference amounts to zero (IPCC, 2007). As an integral part of sustainable development of the energy-system, the associated GHG-emissions must also develop towards a climate-neutral or $CO_{2\text{-equivalent}}$ -neutral system; implying no adverse emission of GHG throughout the entire energy-system (Lund & Mathiesen, 2009). In this study, this is achieved through renewable energy production and energy-efficiency measures.

Secondly, greenhouse gases are defined as those gaseous constituents (both natural and anthropogenic) of the atmosphere, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth’s surface, the atmosphere itself, and by clouds; causing the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth’s atmosphere (IPCC, 2007). Since emphasis is placed on the identification and reduction of GHG-emissions from anthropogenic origin, the so-called F-gases: chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorinated compounds (PFCs), fluorinated ethers and perfluoropolyethers are include as well. This conforms to the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC), and by extension the European Pollution Release and Transfer Register (E-PRTR) and the Dutch ministries of Economic Affairs, Infrastructure and Environment (IPCC, 2007; Amann et al., 2008; Ministerie van Infrastructuur en Milieu, 2013). Since these GHGs absorb different amounts of heat over varying lengths of time, an index based upon these respective properties in the present-day atmosphere, relative to that of CO_2, integrated over a chosen time horizon of 100 years is utilized in order to reflect these varying properties. The resulting ratio is defined as the Global Warming Potential (GWP) of said GHGs and effectively allows for conversion of various gases into their equivalent amounts of CO_2 or CO_{2eq}. This CO_{2eq} thus represents the combined effect of the varying time-scales in which these gases persist in the atmosphere, combined with their relative effectiveness in absorbing outgoing thermal infrared radiation. Expressing the GHG-emissions in terms of CO_{2eq} therefore allows for meaningful quantification, tallying and comparison of these different GHGs (IPCC, 2007). The relevant (anthropogenic) GHG emissions and their conversion factors to standardized CO2-equivalent are presented in Table LIII of the appendix and correspond to those utilized in Dutch (municipal) climate-policies and associated databases (Ministerie van Infrastructuur en Milieu, 2013).

Thirdly, renewable energy is defined as energy derived out of renewable sources without entailing adverse production of GHG through the production, supply and usage of said energy and thus forms an integral part of sustainable development (Lund & Mathiesen, 2009). A general overview of these sources with respect to the Netherlands is provided for in Table I.

Renewable Energy Source	**Renewable Energy Technology**
Wind	**a) Large Scale Wind turbines** **b) Urban Windmills**
Solar	**a) Photovoltaic systems (PV-cells)** **b) Thermal systems (Solar collectors)**
Hydro	a) Hydro power plants b) Hydrothermal power plants
Tidal	Tidal power plants
Waves	Wave-based power plants
Geothermal	a) Geothermal power plants **b) Directly as heat/cold storage**
Biomass	**Thermal conversion: burning, gasification and pyrolysis**
	Biological conversion: Fermentation
	Deployed as transport fuel

Table I - Overview of renewable energy sources and associated technologies applicable to the Netherlands (Buck et al., 2010)

Not all these potential sources apply to the municipalities of Utrecht and de Bilt. For obvious reasons hydro-, tidal-, and wave-based power plants are not applicable to landlocked municipalities. In addition, a petro-physical study conducted by Fugro Robertson (2010) concluded that the potential geothermal energy (at a maximum depth of 2 kilometre) required for viable geothermal power plants is not sufficient throughout the Province of Utrecht (which contains the respective municipalities of Utrecht and De Bilt). Therefore, the focus is placed on wind, solar, biomass and geothermal heat/cold storage.

Fourthly, the concepts relating to energy-efficiency are based on European Council's energy efficiency directive (2006). Herein, energy-efficiency is defined as the relation between an obtained service, good or energy and the respective energy required as input. Energy efficiency improvement thus implies an increase in energy end-use efficiency as a result of technological, behavioural and/or economic changes. Energy savings, signifies an amount of saved energy determined by measuring and/or estimating consumption before and after implementation of one or more energy efficiency improvement measures, whilst ensuring normalisation for external conditions that affect energy consumption.

Finally, the selected type of potential (e.g. Theoretical, Technical or Economic) is the ‘maximal realisable potential’. This is defined as that part of the technical potential that can be achieved utilizing available technologies within a given time period, whilst reflecting constraints in the practical supply of these technologies that arise through scarcities and market processes (Harmelink et al., 2010). This type of potential conforms to those sources constituting the identified energy-efficiency and sustainable energy options as applied in this study.

3.2. DEMARCATION: THE DUTCH MUNICIPAL GUIDELINES

In the strict sense, Dutch municipalities are deemed responsible for all GHG-emissions associated with the production and usage of energy within their borders, as well as those emissions that are produced outside these borders as a consequence of activities within them (Korver & Huffelen, 2014). In order to meaningfully and controllably set-up municipal energy and GHG-policies, inventorying said emissions into a quantified overview is deemed an imperative initial step (Reap et al., 2008; Ministerie van Infrastructuur en Milieu, 2013).

Adhering to this, the Dutch government has published the “Handboek Monitoring broeikasgasemissies en hernieuwbare energie bij lokale overheden”, specifically relating to the construction of these municipal energy and GHG inventories in a *standardized* manner, allowing for comparison between municipalities and implying lowered developmental costs. These guidelines have been commissioned by the Dutch Ministry of Infrastructure and Environment and have been drafted in conjunction with Dutch municipalities, provinces and knowledge-institutes through consultations, expert meetings and sounding board conferences. Additionally, they conform to overarching international guidelines, such as: the Greenhouse Gas-protocol for companies and the ICLEI International Local Government GHG emissions Analysis Protocol (IEAP), and are broadly accepted as appropriate tools (Ministerie van Infrastructuur en Milieu, 2013).

Required Data and the Klimaatmonitor

All centrally available data relating to establishing such an inventory has been made available by the Dutch government and is freely accessible at www.klimaatmonitor.databank.nl. The data as presented herein is generally based on the following:

- GHG-emissions as a consequence of gas and electricity-usage are based on data from bottom up measurements
- GHG-emissions as a consequence of district heating (housing) are based on data extrapolations modelled after the gas-usage of households
- GHG-emissions as a consequence of collected domestic waste are based on data from bottom up registrations
- GHG-emissions as a consequence of transportation are based on data modelled after a top down division of national aggregates
- GHG-emissions as a consequence of carbon trading EUETS-companies are based on bottom up individually reported data

Utilizing the data as presented on KlimaatMonitor allows for the establishment of a general energy- and GHG-balance. Most data is available for the period 2008-2014.

Sectors and Kyoto-gases

In accordance with (inter)national guidelines, the available data is grouped into multiple main sectors. The components (i.e. sub-sectors) hereof conform to the general classification of energy-systems as propounded by a plethora of documents, such as the European Energy Trends (Capros et al., 2010; European Commission, 2014), and thus align smoothly with international guidelines and corresponding scientific literature. These sectors are presented conjointly with their respective anthropogenic GHG-emissions in Table II (full list of Kyoto-gases provided in Table LIII of the appendix).

Main Sector	**Sector**	**Emissions**
Building Environment	Consumers	CO_2
	Commercial Services	CO_2
	Public Services	CO_2
	Sewage Treatment Plants (RWZI's)	CO_2, Methane, Nitrous Oxide
Industry & Energy	Chemical Industry	CO_2, Nitrous Oxide, Fluorinated Gases (F-gases)
	Other Industry	CO_2, Nitrous Oxide, Fluorinated Gases (F-gases)
	Waste Disposal	CO_2, Methane
	Energy Sector	CO_2, Methane
	Construction	CO_2
Agricultural	Greenhouse Cultivation	CO_2, Methane
	Other Cultivation	CO_2, Methane, Nitrous Oxide
Transport	Road Transport	CO_2
	Rail Transport	CO_2
	Shipping	CO_2
	Mobile Equipment	CO_2

Table II - Sectors and Corresponding Emissions (Ministerie van Infrastructuur en Milieu, 2013)

Data-accuracy: Tier-Levels

The available data is divided into three tier-levels, characterised by varying complexities specific to data collection, processing and presentation (IPCC, 1996). Reflective of the lowest level of accuracy, Tier 1 utilizes analysis based on standardized information primarily derived from registration data. Herein, national aggregates are distributed amongst the modelled respective municipalities. An example would include the municipal transport-emissions that are derived from a model revolving around national transport-emissions and municipal transport-intensities. Tier 2 includes calculations based on activity-levels and their associated emission factors. For instance, the amount of units of a certain livestock multiplied by the emission factor per unit. Finally, Tier 3 includes data based on actual measurements and is the most accurate.

A combination of data from Tier 1,2 and 3 is utilized, aiming for the highest level wherever possible in an attempt to obtain the highest possible degree of certainty whilst limiting the risks associated with uncertain data usage and ideally further minimization off, the risk of double-counting or misinterpretation (Ministerie van Infrastructuur en Milieu, 2013).

Demarcation – Questions of Responsibilities?

The municipal GHG-sources are classified into three scopes, according to (inter)national guidelines (Reap et al., 2008; Ministerie van Infrastructuur en Milieu, 2013). This division according to scope allows for more accurate quantitative electricity, heat and emission analysis and aims to eliminate double-counting or misinterpretation of data. This demarcation is presented in Table III.

Scope Level	**Demarcation**
1	Those GHG emissions that are emitted on municipal territory (e.g. those emissions related to the heating of the building stock)
2	Those GHG emissions resulting from the production of heat and electricity that is supplied within the municipal boundaries but is produced outside of them (e.g. those emissions resulting from electricity production that is physically located outside of the municipal boundaries)
3	Those GHG emissions that are emitted outside of the municipal boundaries as a direct consequence of activities of municipal inhabitants (e.g. those emissions as a result of waste-disposal outside of municipal boundaries)

Table III - Scope Level and Demarcation (Ministerie van Infrastructuur en Milieu, 2013)

However, since inventorying a complete representation of produced energy and emitted GHGs requires the allocation of disproportionate amounts of resources, a standardized selection conform Dutch municipal guidelines is supplied based on the compromise between municipal influence, responsibility and the potential for meaningful comparison and presented in Table IV. It is explicitly noted that, the sewage treatment plants (RWZI) of Utrecht and De Bilt are located within the municipal borders, and the RWZI of Utrecht also supplies energy derived out of biogas (Stichting Nederlandse Watersector, 2015a & 2015b). Therefore, herein, scope 1 also *includes* sewage treatment and scope 3 is emitted completely (Ministerie van Infrastructuur en Milieu, 2013).

Scope Level	**Standardized Demarcation**
1	*Includes* all electricity, heat and GHG-emissions produced within the municipal boundary, explicitly *excluding* the production of electricity, railway transport, air-traffic, domestic and international shipping, and highways (>100 km/h).
2	*Includes* the external production of electricity, heat and GHG-emissions as required by the municipality and *excludes* that part of electricity production intended for railway transport
3	*Includes* railway transport, air traffic, domestic and international shipping and external waste disposal. Scope 3 is deemed outside of the scope of the current research.

Table IV - Standardized Selection of Scope Level and Demarcation (Ministerie van Infrastructuur en Milieu, 2013)

A complete overview of the main sectors, sub sectors, GHG-emissions, scope-level and tier-level as utilized in the present study is provided in Table V.

Main Sector	**Subsector**	**GHG-emissions**	**Scope-level**	**Tier-level**
Building Environment	Consumers	CO_2	1	2
	Commercial Services	CO_2	1	2
	Public Services	CO_2	1	2
	Sewage Treatment Plants (RWZI's)	CO_2, Methane, Nitrous Oxide	1	3
Agriculture	Greenhouse Cultivation	CO_2, Methane	1	2
	Other Cultivation	CO_2, Methane, Nitrous Oxide	1	2
Industry & Energy	Chemical Industry	CO_2, Nitrous Oxide, Fluorinated Gases (F-gases)	1	2
	Other Industry	CO_2, Nitrous Oxide, Fluorinated Gases (F-gases)	1	2
	Waste Disposal	CO_2, Methane	1	2
	Construction	CO_2	1	2
	Energy Subsector	CO_2, Methane	2	2
Transport	Shipping	CO_2	3	1
	Rail Transport	CO_2	3	1
	Road Transport (<100 km/h)	CO_2	1	2
	Mobile Equipment	CO_2	1	2

Table V - Sectors, Corresponding Emissions, Scope- and Tier-level

Herein, effectively all subsectors are grouped into scope 1 with the exception of shipping and railway transport (both scope 3 and therefore omitted from this study) and the energy subsector (scope 2). The associated data that is predominantly classified as Tier-level 2 data, with the exception of the RWZI's (tier-level 3) and the omitted subsectors.

Data: Quantification-method

Quantification of renewably produced energy conforms to three methods: the substitution method, Gross End-Use method, and the primary energy/input method (Buck et al., 2010). In this study, the Gross end-Use method is proposed since this method replaced the substitution method as the national standard and thus conforms with current and future standardized protocols (Ministerie van Infrastructuur en Milieu, 2013).

Herein, the final energy demand forms the basis out of which the relative amount of sustainably produced energy is deduced. This final energy demand corresponds to that part of the produced energy as delivered to the end-users (any energy produced by these end-users is then grouped into the energy-producing sector, or scope 2). The gross end-use includes all necessary energy required in order to produce electricity and heat as well as those losses corresponding to the transportation and transformation of said electricity and heat. It must be explicitly noted that this method does not include any non-energetic usage of fossil fuels nor does it include any usage of so-called reference technologies in its calculations (Buck et al., 2010).

3.3. THE ENERGY-BALANCE

Setting up the Energy –Balance (KlimaatMonitor)

Total annual gas and electricity usage is calculated based on aggregating the reported gas and electricity usage of respective branches following the Standaard BedrijfsIndeling (SBI) division and supplemented by estimates provided by ABF Research where specific data is absent (e.g. omitted due to privacy-issues). This activity-data is supplied through the KlimaatMonitor as derived from the CBS, ECN, PBL, RVO, RIVM and TNO predominantly, based on activity-data as provided by the respective grid-operators. Herein, the public electricity grid data is supplied through the national grid-operator TenneT and the respective regional operators. The activity-data relating to public gas-usage is conveyed through the national gas grid-operators, the Zebragasnetwork and the gas grids from respective regional operators. The activity-data related to corporate (i.e. other than publicly-operated) gas and electricity usage is delivered via the respective corporate energy-networks. This activity-data is then grouped via the aforementioned SBI division. This is a hierarchal classification of economical activities based on the international formats NACE (Nomenclature statistique des activités économiques dans la Communauté Européenne) and ISIC (International Standard Industrial Classification of All Economic Activities) and thus conforms to European and UN frameworks respectively. Herein, 'Bedrijfstak' or 'branche' (i.e. Sector or branch) are commonly used to describe groups and corporations with similar operational *main* activities. Generally, the SBI consists of four to five digits, the first four of which correspond to the NACE and the first two to the ISIC. A drastic revision during 2008 (i.e. SBI 2008) allowed for a more realistic alignment but influenced the affiliation with previous SBI statistics and registers (i.e. SBI'93). Amongst other issues relating to data availability and reliability, this is one of the reasons that 2008 is selected as a first data-point. The general SBI classifications are presented below, as derived from the CBS (2014).

a) Agriculture, forestry and fishing
b) Mining and quarrying
c) Manufacturing
d) Electricity, gas, steam and air conditioning supply
e) Water supply; sewage, waste management and remediation activities
f) Construction
g) Wholesale and retail trade; repair of motor vehicles and motorcycles
h) Transportation and storage
i) Accommodation and food service activities
j) Information and communication
k) Financial institutions
l) Renting, buying and selling of real estate
m) Consultancy, research and other specialized business services
n) Renting and leasing of tangible goods and other business services
o) Public administration, public services and compulsory social security
p) Education
q) Human health and social work activities
r) Culture, sports and recreation
s) Other service activities
t) Activities of households as employers; undifferentiated goods- and service- producing activities of households for own use
u) Extraterritorial organisations and bodies

Gaps, Uncertainties and Estimates in Reported Energy Usage (KlimaatMonitor)

Due to the possible sensitive nature of this data, certain branch information is omitted from the final Klimaatmonitor reports. These gaps in specific branch information would imply an exponential increase of uncertainty with respect to the aggregated (sub)sectors and consequently the total municipal energy usage.

Addressing this issue, ABF Research was tasked with providing branch estimates. The resulting estimates are *not* presented in Klimaatmonitor due to the aforementioned sensitivity of said data in addition to the unknown uncertainty-margins relating to these estimates. The aggregates, however, are displayed since through aggregation the uncertainty margin is greatly reduced.

Herein, the annual data relating to gas and electricity usage are estimated in a top-down way, starting with the highest and ending with the lowest geographical level. First-off, provincial data relating to energy-usage per sector is estimated through crossing the national totals per sector (aggregated over the provinces) with the provincial totals (aggregated over the respective sectors). Herein, known municipal aggregates within provinces supply the lower limits. Secondly, missing municipal data is estimated in a similar manner. The now known provincial totals per sector (aggregated over the municipalities) are crossed with the municipal totals (aggregated over the respective sectors). However, since not all aggregated sector totals are available on the municipal level, these have been estimated analogously utilizing the known municipal sector-data as lower limits.

The following methods have been applied in estimating the unknown energy-usage (i.e. electricity and gas) data:

1. If in the target year the energy-usage of the *other* energy-types are known and in the previous years the energy usages of *both* energy-types are known, then the precentral change from the *other* energy-type is applied to the energy-type to be estimated.
2. If the above is not possible, the proportional energy-usage relative to the sectoral total in the first previous available year is applied to the total energy-usage in the target year.
3. If the above is not possible, the percentage of the first available previous energy-usage of the *other* energy-type with respect to the respective sectoral total is determined. This percentage is subsequently applied to the energy-type to be estimated.
4. If none of the three estimation methods are possible, an initial estimate is provided based on the ratio of the total energy-usage of both energy types with respect to the sectoral aggregate which is always possible

Additionally, the original data includes a certain uncertainty margin since the CBS rounds off their data to 10^3 (=1000), which might relate especially to smaller branches. Furthermore, a small part of the total aggregate (i.e. national) activity data (<0,5%) cannot be designated to the provincial or municipal level, thereby increasing the uncertainty. Fortunately, strictly speaking, the overall uncertainty is estimated at a couple percentages maximum which is deemed acceptable by CBS.

The Current Energy Balances of Utrecht and De Bilt

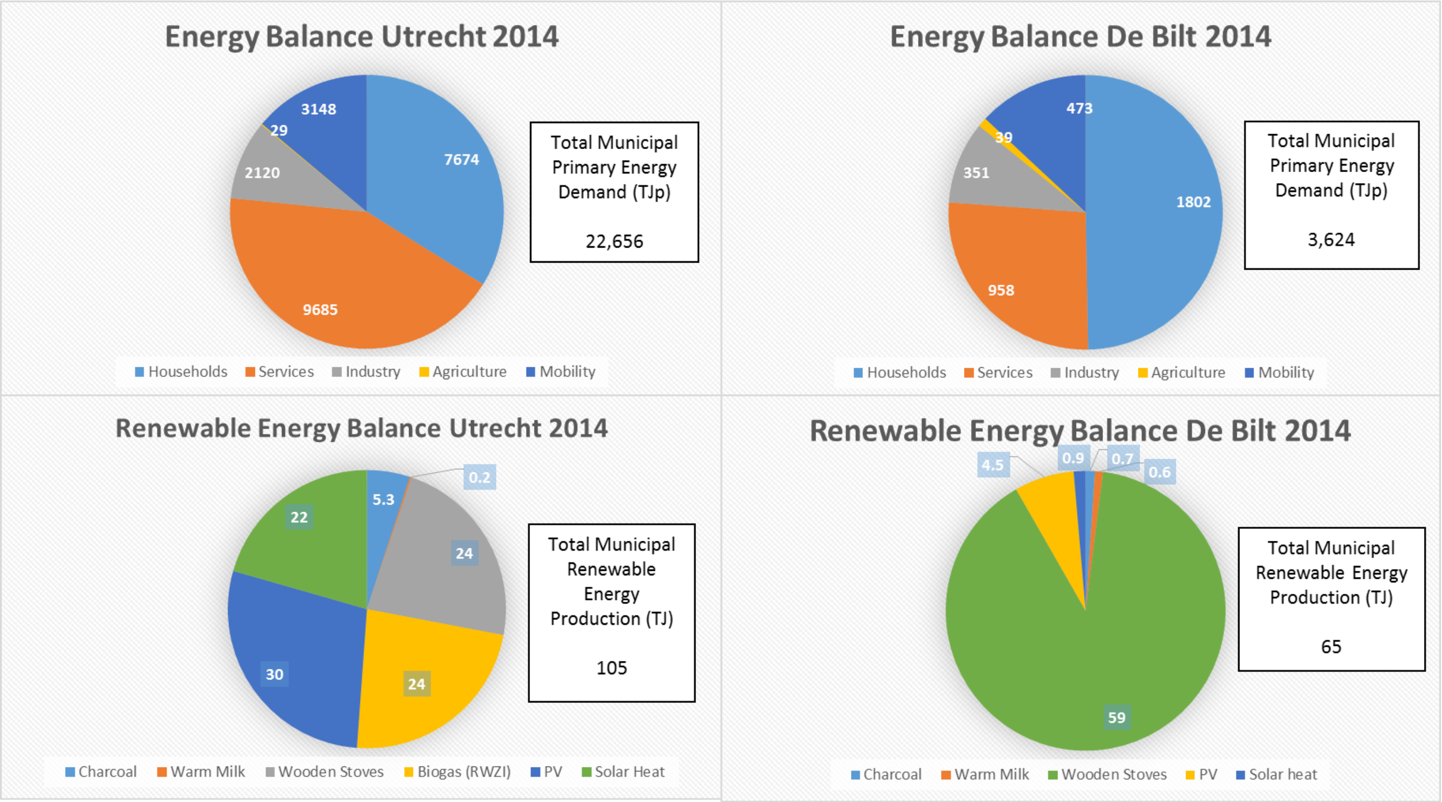


Figure 1 - Current Energy Balances of Municipalities Utrecht and De Bilt

The resulting current (2014) energy balances for the municipalities of Utrecht and De Bilt are provided for in

Figure 1. Herein, the total primary energy demand is 3,624 TJp for De Bilt and 22,656 TJp for Utrecht. The main relative difference in the Energy balances is related to the mobility and service sectors. Herein, De Bilt has a significant proportion of energy demand allocated to the mobility sector whilst the service sector in Utrecht entails the largest proportion of Energy demand. With respect to current renewable energy production, this is fairly low for both municipalities (65 TJ for De Bilt and 105 TJ for Utrecht respectively). Production is more diverse in Utrecht where significant production take place via solar heat, PV-panels, biogas (out of the RWZI) and wooden stoves. De Bilt predominantly produces sustainable heat through wooden stoves while other options are significantly less developed. The discrepancy between the respective energy demands and sustainable energy produced, implies a large required development of sustainable energy production and energy-efficiency measures in order to bridge this gap.

3.4. THE GHG-BALANCE

GHG-Emission Data: Direct Measurements and Taskforce Estimates (KlimaatMonitor)

GHG-emission inventorying revolves around either direct measurements of individually registered industrial corporations, or calculations provided for by taskforces of the respective institutions that are involved in specific sectors and include diffusive emissions.

A large number of Dutch companies are required by law to publish an annual Pollution Release and Transfer Register (PRTR) report stating their respective annual GHG-emissions, and waste disposal. It conforms to international emission-reporting standards and specifically contains the data required by the government to monitor both environmental policies, and corporate environmental performance (VROM, 2009). These are scrutinized by the relevant controlling authorities (provinces, municipalities, waterboards and licensing institutions), aggregated and stored in a database. They are supplemented by GHG-emission data as supplied by businesses on a voluntary basis (e.g. through specific environmental agreements or as part of corporate social responsibility). The sum of this collection is dubbed the ER-Individueel or ER-I database and forms the basis for specific emission calculations per energy-type in the sectors: Industry, Energy, Refineries and Waste Disposal. With respect to emission calculations relating to the other sectors; these are determined through employing diverse statistical data (as provided for by the respective taskforces), emission-factors, international scientific literature and model-based calculations. In-depth and meticulous clarifications for the particular methods used within the different (non-industrial) sectors is located on the Klimaatmonitor website.

These taskforces are responsible for collecting and processing data as well as developing and conducting robust emission-calculations that correspond with (inter)national scientific methods and guidelines relating to GHG-inventorying. An overview, short description and the constituting institutions of these taskforces are presented in Table VI, with special attention direct towards the Taskforce Spatial Distribution in the section 'Dutch Taskforce Spatial Distribution' of the appendix.

Taskforce	**Description**	**Sources**
Taskforce Energy, Industry and Waste disposal (ENINA)	Taskforce ENINA focusses on determining the atmospheric GHG emissions from the sectors: Energy, Industry and waste disposal	RIVM, PBL, TNO, CBS and RVO
Taskforce Transport	Taskforce Transport focusses on determining the atmospheric, aquatic and terrestrial GHG emissions from Air-, water-, and road-transport	RIVM, PBL, TNO, CBS, RWS-WVL and Deltares
Taskforce Agriculture and Land usage	Taskforce Land Usage focusses on determining the terrestrial and atmospheric GHG emissions from agricultural practices and other land usage	RIVM, PBL, LEI, Alterra and CBS
Taskforce Method Developing Water-emissions (MEWAT)	Taskforce MEWAT focusses on determining aquatic GHG emissions from multiple sectors	RWS-WVL, Deltares, RIVM, PBL, CBS and TNO
Taskforce Other Sources (WESP)	Taskforce WESP focusses on determining GHG emissions resulting from consumer usage and those resulting from the sector Commerce, Service and Government (Handel, Diensten en Overheid HDO)	RIVM, TNO and CBS
Taskforce Spatial Distribution	Taskforce spatial distribution focusses on determining the total national emissions through geographical divisions.	RIVM, TNO, LEI and PBL

Table VI - Dutch Taskforces GHG Emission Registration

The Current GHG Balances of Utrecht and De Bilt

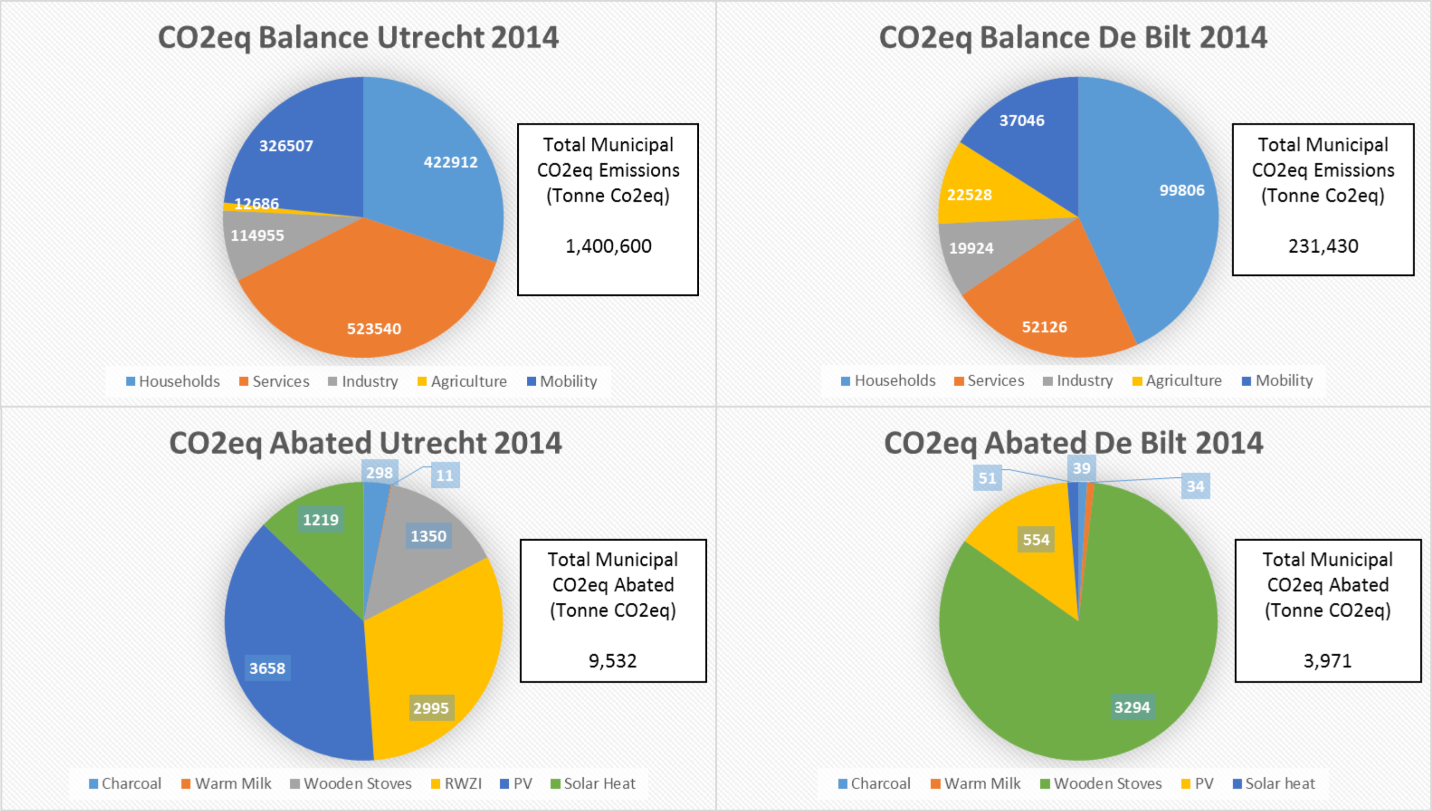


Figure 2 - The Current GHG Balances of Utrecht and De Bilt

The derived current GHG balances of Utrecht and De Bilt are presented in Figure 2. Herein the total CO_{2eq} emitted amounts to 1,400,600 Tonne for Utrecht and 231,430 Tonne for De Bilt. The distribution hereof is reflective of the respective municipal energy demands as set out in chapter 3.3 with the notable exception for those emissions resulting from agricultural practices in De Bilt. These amount to a significant fraction of total emissions when compared with the energy demanded by this sector due to substantial emissions of CH_4 an N_2O. The abated GHG emissions through sustainable energy production (9,532 Tonne for Utrecht and 3,971 Tonne for De Bilt) are also reflective of the distribution hereof as presented in

Figure 1.

It is noted that the fairly large abatement attributed to PV-panels and the RWZI is credited by the fact that these produce renewable electricity instead of renewable heat and the abated GHG emissions are thus based on those GHGs that would be emitted should this electricity be produced in conventional power plants utilizing the current national efficiencies and associated carbon intensities. This is elucidated upon in the upcoming chapter 3.5.

3.5. SETTING UP THE REFERENCE PATHWAYS

Reference Pathways: The National Energy-Exploration Documentation

Assessing the potential future impact of various additional energy-, and GHG-abatement measures aimed at achieving energy- neutrality requires at least two scenario types: a baseline or reference pathway, reflective of expected macro developments without said abatement measures, and a policy pathway reflective of current expected macro developments *including* said abatement measures and their effects on the (development of the) energy-system (Nauclér & Enkvist, 2009). In this research the reference pathway provided for the municipalities until 2030 conforms to the Dutch national energy-exploration documentation. Herein, based on the results of a collaboration between the Dutch Energy-Research-Centrum (ECN), central planning bureau (PBL), Central Bureau of Statistics (CBS) and the service for entrepreneurial activities (RVO), those expected developments relating to the Dutch energy-system are presented (M. Hekkenberg & Verdonk, 2014).

The 'Intended Policies' Pathway in the National Energy-Exploration Documentation

The ECN supplies two such reference pathways, differing solely with respect to which policy instruments and agreements are included. Herein, 'Established policies' ('EP') relates to those currently established (as of April 2014) binding agreements and legislative measures; while 'intended policies' ('IP') also includes those agreements and measures that are not formally established but are deemed sufficiently concrete and have been made publicly available (as of May 2014). These agreements and measures are generally of a more stringent character, entailing larger energy-reductions and lowered GHG-emissions through various means, when compared to the 'established policies' pathway.

Exemplifying, whilst drafting the National Energy-exploration Documentation, the Dutch Energy-agreement (Energieakkoord) was signed, entailing numerous energy-related covenants and involving a large number of public organisations (SER, 2013). This agreement is intended to have a large effect on the developments of the national energy-system. Nonetheless, at the time of writing the National Energy Exploration documentation, most of these agreements and legislative measures were not sufficiently concrete to be included in the 'established policies' pathway. Fortunately, most of these 'Energieakkoord' policies have been included in the 'intended policies' pathway; reflective of uncertainties herein through the usage of value-ranges (Michiel Hekkenberg & Verdonk, 2014a). Being the most reflective of future Dutch and European policies as well as international developments, this IP projection is selected as the reference scenario.

It is assumed that all established and intended policy measures are enforced consistently throughout their intended timeframe unless explicitly stated otherwise. The additional costs in this 'IP are assumed at zero for all identified options, providing a baseline for the additional costs determined in the second scenario, set out in chapter 3.7. The expected developments are taken at face value and any assessment of them is deemed beyond the range of the current research. Indicative IP national sectoral annual reduction percentages are provided in Table LIX of the Appendix.

Anticipated proxy data relating to national macro-economic developments specific to the 'Intended Policies' reference pathway are presented below in Table VII. General national demographic developments are presented in Table LV of the Appendix.

Key-figures	**2000**	**2010**	**2012**	**2020**	**2030**
				Intended Policies	
Gross domestic product (index, 2000 = 100)	100	113	113	124	147
Final energy usage (PJ)	2,245	2,215	2,185	2,132	2,161
Energy reduction percentage (annual %)	-	1.1	-	1.2	0.7
Renewable energy as part of final energy usage (%)	1.4	3.7	4.5	12.4 (2023: 15.1)	20
GHG-emissions (Mt CO_{2eq}*)*	213	209	192	176	158

Table VII - Key Figures Dutch Energy Development (M. Hekkenberg & Verdonk, 2014)

On a national level, the gross domestic product (GDP) is expected to rise continuously, with the GDP of 2030 expected to be almost 150% of the GDP in 2000. Fortunately, the final energy usage is not expected to follow this trend and drops by 1.2% annually until 2020 and by 0.7% until 2030 from the 2,245 (PJ) in 2000 to 2,161 (PJ) in 2030. The intended percentage of renewable energy as part of the final energy consumption is framed to reach 20% in 2030, whilst the associated GHG-emissions drop correspondingly. These projected developments conform to established and intended (inter)national (predominantly European) agreements and legislation (Capros et al., 2012; Hekkenberg & Verdonk, 2014a).

Here, the required projected wholesale price of oil, gas, coal and electricity, are presented in Table VII based on projection provided by the International Energy Agency (IEA) which are assumed to apply to the municipal systems of Utrecht and De Bilt.

	Description	**Unit**	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Oil	North Sea Brent	US dollar per barrel	113	112	107	127	131	143
Gas	Wholesale price	Euro per m^3	0.24	0.26	0.24	0.30	0.30	0.32
Coal	Import 'ketelkolen' (kettle coal) Nederland	Euro per tonne	81	64	63	89	91	94
Electricity	Wholesale price	Euro per MWh	52	43	43	59	60	59

Table VIII - Projected Oil, Gas, Coal and Electricity Prices (IEA, 2013)

Additional figures and projections relating to the impact of (inter)national energy market developments until 2030 and their expected impact on the municipal energy systems are provided for in detail in the "General Developments 'Intended Policies': Energy-markets until 2030" section of the appendix. It is explicitly noted that key figures relating to developments in the respective national and municipal population are provided for in table LV and LVI of the appendix.

General Developments 'Intended Policies': Emission Factors, Energy Content and Power Generation Efficiencies until 2030

Relevant proxy-data revolving around emission and conversion factors for fuels (predominantly those utilized in the transport sector) and their specific energy content have been provided for (Table IX) through the KlimaatMonitor, in collaboration with the Dutch institutions 'Stichting Klimaatvriendelijk Aanbesteden en Ondernemen' (SKAO), Connekt and Stimular (2011). The respective emission factors relate fuel consumption, expressed in volume (litres), to the amount of CO_{2eq} emissions expressed in Kg as a result of the combustion of said fuels. The specific energy content relates the amount of energy that is released through combustion to the volume (litres) of the fuel that is combusted. It is noted that the energy content of 'stookolie' (light fuel, sometime referred to as 'huisbrandolie') is deemed identical to those attributed to diesel fuel while the emission factor varies slightly. Furthermore, the energy content of electricity effectively converts the unit of measurement from kWh (kilowatt-hours) to Gigajoules. The presented values are *identical* for both municipalities since they reflect basic unwavering physical characteristics and, for the same reason, are assumed constant with respect to the projections towards 2030 (and have remained constant for the preceding period as stated in the KlimaatMonitor).

Description	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Emission factor diesel in Kg/l [Kg]	3.14	3.14	3.14	3.14	3.14	3.14
Emission factor gasoline in Kg/l [Kg]	2.78	2.78	2.78	2.78	2.78	2.78
Emission factor LPG in Kg/l [Kg]	1.86	1.86	1.86	1.86	1.86	1.86
Emission factor 'Stookolie' (light fuel) in Kg/l [Kg]	3.12	3.12	3.12	3.12	3.12	3.12
Energy content of natural gas (LHV) in MJ/m3 [MJ]	31.65	31.65	31.65	31.65	31.65	31.65
Energy content of electricity in GJ/kWh [GJ]	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036
Energy content of electricity in TJ/kWh [TJ]	$3.6*10^{-6}$	$3.6*10^{-6}$	$3.6*10^{-6}$	$3.6*10^{-6}$	$3.6*10^{-6}$	$3.6*10^{-6}$
Energy content diesel in MJ/l [MJ]	35.87	35.87	35.87	35.87	35.87	35.87
Energy content gasoline in MJ/l [MJ]	31.68	31.68	31.68	31.68	31.68	31.68
Energy content LPG in MJ/l [MJ]	24.45	24.45	24.45	24.45	24.45	24.45
Energy content 'Stookolie' (light fuel) in MJ/l [MJ]	35.87	35.87	35.87	35.87	35.87	35.87

Table IX - Emission Factors and Energy Contents Projections of Diesel, Gasoling, LPG, Stookolie, Natural gas and Electricity (SKAO, Connekt, & Stimular, 2011)

Since no municipal-specific information is provided with regard to the future efficiency of (conventional) thermal power generation, this data is derived out of the 'EU Energy, Transport and GHG Emissions - Trends to 2050' as provided by the European Commission (2014b). Herein, solely the data points as stated in Table X have been provided so that the missing data points are interpolated linearly based on the known entries. This efficiency is an average value for the whole of the Netherlands and is assumed to hold for both municipalities.

With respect to the associated Dutch national carbon intensities relating to power generation, these are based on linearly extrapolated trends (from 2013 onward), derived out of the KlimaatMonitor as supplied by the CBS. These trends are then checked for consistency with the national projections as provided through the 'EU Energy, Transport and GHG Emissions - Trends to 2050' as provided by the European Commission (2014b) (see Table X**Error! Reference source not found.**). Herein it becomes evident that discrepancies arise. In this study, the carbon intensities as derived out of the KlimaatMonitor are selected since these have been supplied by the Dutch Bureau of Statistics and are therefore deemed more reliable. The emission factor of natural gas is also derived out of the KlimaatMonitor and linearly extrapolated from 2013 onward. Due to a very limited discrepancy (i.e. 2%) between 2005, 2014 and 2030, these values are assumed to hold. This data is utilized in order to determine the gross primary energy requirements and associated CO_{2eq} emissions per sector as produced centrally in conventional fossil-fuel power plants. The linear interpolations are provided for in Table LVIII of the appendix.

Year	**Efficiency of gross thermal power generation (%) ‘EU Trends’**	**Emission Factor of Natural Gas (Tonne/m^3) ‘KlimaatMonitor’**	**Carbon Intensity of Electricity and Steam Prodcution (Tonne CO_{2eq}/kWh) ‘KlimaatMonitor’**	**Carbon Intensity of Electricity and Steam Prodcution (Tonne CO_{2eq}/kWh) ’EU Trends’**
2005	41.5	0.001795	0.00051	0.00035
2010	44.6	0.001788	0.00046	0.0003
2015	43.2	0.001779	0.000433	0.0003
2020	42.3	0.001773	0.000391	0.00026
2025	42.4	0.001766	0.000349	0.00026
2030	43.7	0.001759	0.000307	0.00023

Table X - Efficiency of Dutch gross thermal power generation, emission factor of natural gas and carbon intensities; including linear interpolations (KlimaatMonitor; European Commission, 2014b)

3.6. ENERGY DEMAND PROJECTIONS ‘INTENDED POLICIES’

The energy demand projections until 2030 will be provided per sector on the basis of annual reduction percentages. These are specified to key indicators, predominantly relating to their respective sectoral energy-demand and associated GHG-emissions (unless stated otherwise). These projections are derived out of national statistics and checked for trend-consistency with the data as derived out of KlimaatMonitor. Herein, for both municipalities, these observed municipal values from 2008 to 2014 are checked with the provided national trends for the same period. When these trends exhibit large discrepancies, the current trends derived out of the KlimaatMonitor are assumed to hold until 2030. Discrepancies have been identified with respect to the developments in the sector Agriculture and Industry and will be elucidated on in more detail.

‘Intended Policies’ - Households

With respect to the sector households, the national average gross end-use of electricity and gas per household is calculated based on the data as provided in Table XI. It is noted that, As a general rule, households with a higher population density (i.e. ‘larger’ households) are deemed more energy-efficient when compared to those households with a low density (i.e. ‘smaller’ households) so that a smaller household will generally require more energy per resident than a larger household. As of 2014, the household density of Utrecht is 1.91 and 2.20 for De Bilt whereas the national average amounted to 2.20 (PBL & CBS, 2013b; PBL & CBS, 2013a).

Households	**2000**	**2005**	**2010**	**2012**	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Private households (million)	6.8	7.1	7.4	7.5	7.6	7.6	7.7	8.0	8.1	8.4
Gross end-use electricity (PJ)	72	78	83	84	82	80	79	79	78	82
Gross end-use natural gas (PJ)	398	350	350	326	334	329	324	294	288	273
$CO2_{eq}$ emissions (Mtonne)	23	20	20	19	19	19	19	17	16	15

Table XI – ‘Intended Policies’ Projections the Gross End-use of Electricity and Gas and associated CO_{2eq} emissions in Households (Hekkenberg & Verdonk, 2014b)

Utilizing this data, an average gross end-usage in MJ per household is supplied for both electricity and gas in Table XII. Additionally, change percentages are provided for each interval are derived:

Households	**2000**	**2005**	**2010**	**2012**	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Change in households (%)		4.41	4.23	1.35	1.33	0.04	1.32	3.90	1.25	3.70
Average Gross End-Use of Electricity & Gas [MJ/household]	69,118	60,282	58,514	54,667	54,737	53,816	52,338	46,625	45,185	42,262
Change (%)		-12.8	-2.9	-6.6	0.1	-1.7	-2.7	-10.9	-3.1	-6.5
Average Gross End-Use of Electricity [MJ/household]	10,588	10,986	11,216	11,200	10,789	10,526	10,260	9,875	9,630	9,762
Change (%)		3.8	2.1	-0.1	-3.7	-2.4	-2.5	-3.8	-2.5	1.4
Average Gross End-Use of Gas [MJ/household]	58,529	49,296	47,297	43,467	43,947	43,289	42,078	36,750	35,556	32,500
Change (%)		-15.8	-4.1	-8.1	1.1	-1.5	-2.8	-12.7	-3.3	-8.6
Average $CO2_{eq}$ emissions (Tonne/household)	3.4	2.8	2.7	2.5	2.5	2.5	2.5	2.1	2.0	1.8
Change (%)		-16.7	-4.1	-6.3	-1.3	0.0	-1.3	-13.9	-7.0	-9.6

Table XII – Annual changes in Number of Household and Average Gross End-Use of Electricity and Natural Gas and Associated CO_{2eq} emissions

‘Intended Policies’ - Services (Public and Commercial)

With respect to the sector services (both public and commercial), the national average gross end-use of electricity and gas per square meter of service-housing is calculated based on the data as provided in Table XIII

Services	**2000**	**2005**	**2010**	**2012**	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Total Surface Area (Million m^2)	382	417	456	464	467	471	475	495	502	522
Gross end-use electricity (PJ)	110	117	123	133	135	135	135	129	125	124
Gross end-use natural gas (PJ)	118	145	154	164	158	157	156	145	138	124
$CO2_{eq}$ emissions (Mtonne)	7	9	9	10	9	9	9	8	8	7

Table XIII – ‘Intended Policies’ Projections of the Surface Area and Gross End-use of Electricity and Natural Gas and Associated CO_{2eq} Emissions in the Service Sector (Michiel Hekkenberg & Verdonk, 2014b)

Utilizing this data, an average electricity and gas gross end-usage in MJ per square meter of ‘Service-area’ as well as the changes herein expressed as a percentage per period are provided in Table XIV

Services	**2000**	**2005**	**2010**	**2012**	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Change in surface area (%)		9.16	9.35	1.75	0.65	0.86	0.85	4.21	1.41	3.98
Average Gross End-Use of Electricity & Gas [MJ/m^2]	596.9	628.3	607.5	640.1	627.4	620.0	612.6	553.5	523.9	475.1
Change (%)		5.3	-3.3	5.4	-2.0	-1.2	-1.2	-9.6	-5.4	-9.3
Average Gross End-Use of Electricity [MJ/ m^2]	288.0	280.6	269.7	286.6	289.1	286.6	284.2	260.6	249.0	237.5
Change (%)		-2.6	-3.9	6.3	0.9	-0.8	-0.8	-8.3	-4.5	-4.6
Average Gross End-Use of Gas [MJ/ m^2]	308.9	347.7	337.7	353.4	338.3	333.3	328.4	292.9	274.9	236.5
Change (%)		12.6	-2.9	4.7	-4.3	-1.5	-1.5	-10.8	-6.2	-13.6
Average $CO2_{eq}$ emissions (Tonne/ m^2)	0.018	0.022	0.020	0.022	0.019	0.019	0.019	0.016	0.016	0.013
Change (%)		17.8	-8.6	9.2	-10.6	-0.8	-0.8	-14.7	-1.4	-15.9

Table XIV – Annual Changes in Average Gross End-Use of Electricity and Natural Gas and Associated CO_{2eq} emissions of the Service Sector

‘Intended Policies’ - Transportation

With respect to the transportation sector, the national number of automobiles, average gross end-use of oil-products, electricity, gas and biofuels is projected based on the data as provided in Table XV.

Transportation	**2000**	**2005**	**2010**	**2012**	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Number of Automobiles (including commercial vehicles) (million)	7.2	8.1	8.7	8.9	9.0	9.0	9.3	9.9	10.3	11
Oil-products (PJ)	508	531	520	505	502	495	483	462	459	453
Natural gas (PJ)	0	0	0	1	1	1	1	2	3	5
Electricity (PJ)	6	6	6	6	7	7	8	10	12	17
Biofuels (PJ)	0	0	10	14	14	18	26	37	36	36
$CO2_{eq}$ emissions (Mtonne)	37	39	38	37	37	36	35	34	34	33

Table XV – ‘Intended Policies’ Projections of the Vehicle Kilometres and Gross End-use of Oil-Products, Electricity, Gas, Biofuels and Associated CO_{2eq} emissions in the Transportation Sector (Michiel Hekkenberg & Verdonk, 2014b)

Utilizing this data, an average oil, electricity, gas and biofuels gross end-usage in MJ per vehicle as well as the changes herein expressed as a percentage per period are provided in Table XVI.

Transportation	**2000**	**2005**	**2010**	**2012**	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Average Total Gross End-Use of Oil-products, Electricity and Gas [MJ]	71,131	66,385	61,492	58,939	58,488	58,174	55,879	51,703	49,749	45,994
Change (%)		-6.7	-7.4	-4.2	-0.8	-0.5	-3.9	-7.5	-3.8	-7.5
Change in total number of automobiles (%)		11.9	7.8	2.4	0.4	0.0	3.5	6.6	3.7	8.4
Average Gross End-Use of Oil-products [MJ/vehicle]	70,301	65,644	59,657	56,586	56,033	55,271	52,104	46,745	44,774	40,773
Change (%)		-6.6	-9.1	-5.1	-1.0	-1.4	-5.7	-10.3	-4.2	-8.9
Average Gross End-Use of Gas [MJ/vehicle]	0	0	0	112	112	112	108	202	293	450
Change (%)					-0.4	0.0	-3.4	87.6	44.6	53.8
Average Gross End-Use of Electricity [MJ/vehicle]	830	742	688	672	781	782	863	1012	1171	1530
Change (%)		-10.7	-7.2	-2.3	16.2	0.0	10.4	17.2	15.7	30.7
Average Gross End-Use of Biofuels [MJ/vehicle]	0	0	1147	1569	1563	2010	2805	3744	3512	3240
Change (%)				36.7	-0.4	28.6	39.6	33.5	-6.2	-7.7
Average $CO2_{eq}$ emissions (Tonne)	5.1	4.8	4.4	4.1	4.1	4.0	3.8	3.4	3.3	3.0
Change (%)		-5.8	-9.6	-4.9	-0.4	-2.7	-6.1	-8.9	-3.6	-10.4

Table XVI – Annual Change in Average Gross End-Use of Oil-products, Natural Gas, Electricity, Biofuels and CO_{2eq} emissions in the Transportation Sector

‘Intended Policies’ - Agriculture

With respect to the agricultural sector, the national average gross end-use of oil-products, electricity, gas and biofuels per square meter of agricultural land is calculated based on the data as provided in Table XVII.

Agriculture	**2000**	**2005**	**2010**	**2012**	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Natural gas and Electricity (PJ)	152	144	170	161	168	163	159	147	147	148
Change (%)		-5.3	18.1	-5.3	4.3	-3.0	-2.5	-7.5	0.0	0.7
Natural gas (PJ)	134	123	138	130	136	130	126	111	110	108
Change (%)		-8.2	12.2	-5.8	4.6	-4.4	-3.1	-11.9	-0.9	-1.8
Gross end-use electricity (PJ)	18	21	32	31	32	33	33	36	37	40
Change (%)		16.7	52.4	-3.1	3.2	3.1	0.0	9.1	2.8	8.1
CO_2 emissions (Mtonne)	8	7	8	7	8	7	7	6	6	6
Change (%)		-12.5	14.3	-12.5	14.3	-12.5	0.0	-14.3	0.0	0.0
CO_{2eq}-emisisons from CH_4	9	9	10	9	10	10	10	9	9	9
Change (%)		0.0	11.1	-10.0	11.1	0.0	0.0	-10.0	0.0	0.0
CO_{2eq}-emisisons from NO_2	9	8	7	7	7	7	7	7	7	7
Change (%)		-11.1	-12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table XVII – ‘Intended Policies’ Projections of the Gross End-use of Electricity, Gas and CO2eq Emissions in the Agricultural Sector (Michiel Hekkenberg & Verdonk, 2014b); including their change percentages

However, no projected key indicator data is presented relating to national agricultural surface area changes in Table XVII. Fortunately, previous data (derived out of the KlimaatMonitor, see Table XVIII) relating to the agricultural surface area changes for 2000-2012 yield indicative results with respect to both the national level, and the municipalities of Utrecht and De Bilt.

Region	Indicators	2000	2003	2006	2008	2010	2012
Netherlands	Total Agricultural area (ha)	2,326,047	2,304,074	2,285,799	2,275,827	2,264,376	.
	Change (%)	-	-0.94	-0.79	-0.44	-0.50	-
	Agricultural greenhouse cultivation (ha)	14,981	15,660	16,241	16,791	16,622	.
	Change (%)	-	4.53	3.71	3.39	-1.01	-
	Other Agricultural area (ha)	2,311,066	2,288,414	2,269,558	2,259,037	2,247,754	.
	Change (%)	-	-0.98	-0.82	-0.46	-0.50	-
De Bilt	Total Agricultural area (ha)	590	3,499	3,499	3,479	3,461	3,434
	Change (%)	-	493.05	0.00	-0.57	-0.52	-0.78
	Agricultural greenhouse cultivation (ha)	-	7	7	7	6	6
	Change (%)	-	-	0.00	0.00	-14.29	0.00
	Other Agricultural area (ha)	590	3,492	3,492	3,472	3,455	3,428
	Change (%)		491.86	0.00	-0.57	-0.49	-0.78
Utrecht	Total Agricultural area (ha)	1,164	3,198	2,709	2,666	2,545	2,454
	Change (%)	-	174.74	-15.29	-1.59	-4.54	-3.58
	Agricultural greenhouse cultivation (ha)	56	54	18	15	13	9
	Change (%)	-	-3.57	-66.67	-16.67	-13.33	-30.77
	Other Agricultural area (ha)	1,108	3,144	2,691	2,651	2,532	2,446
	Change (%)	-	183.75	-14.41	-1.49	-4.49	-3.40

Table XVIII – Annual Changes in Agricultural Area Data as Derived out of the KlimaatMonitor

On the national level there is a slight decrease in total agricultural area, effectively dropping from roughly 2,320,000 hectares in 2000 to 2,230,000 hectares in 2010 with reduction percentages consistently between 0% and -1%. With respect to its constituents, a trade-off between greenhouse cultivation and other types of agriculture is detected. Herein, an increase in greenhouse cultivation is observed (from roughly 15,000 hectares to 16,600 hectares) whereas a decrease in other agricultural areas is perceived (dropping from 2,310,000 hectares to 2,250,000 hectares). The following trends are discerned regarding the national agricultural sector: An annual decrease of total agricultural area (-0.29%), an annual increase in greenhouse cultivation (+1.02%) and an annual decrease in other agricultural areas (-0.30%).

With regards to De Bilt, a disproportioned increase is observed in the period 2000-2003. This period is regarded as an outlier and disregarded. For 2003-2012 the observed municipal trend correspond to the National trends with the exception of the greenhouse cultivation which, in fact, drops slightly. The following trends are applied to the agricultural sector of De Bilt: An annual decrease of total agricultural area of -0.31% is applied, the greenhouse cultivation area is kept constant at 6 hectares while the other agricultural areas decrease with about -0.31% annually.

With regards to Utrecht, the period 2000-2003 is disregarded for the same reasons as those applicable to De Bilt. Generally speaking, large decreasing trends are observed that do not correspond well with the observed national trends. The total agricultural area for Utrecht drops from 3,198 hectares to 2,454 hectares, while greenhouse cultivation areas drop from 54 hectares to 9 hectares. The other agricultural areas also experienced a drop from 3,144 hectares to 2,446 hectares. The following trends are applied to the agricultural sector of Utrecht. An annual decrease of total agricultural area of -1.61%, an annual decrease of -10.13% with regards to the greenhouse cultivation area and, finally, an annual -1.56% decrease of other agricultural area is assumed.

When applied to the projected data as derived out of Table XVII the following projected ‘intended policies’ energy-usages with respect to the agricultural sector, yield the results as presented in Table XIX. The respective percentages relating to changes in Natural gas and Electricity (MJ/ha), Natural gas (MJ/ha), Cogeneration (MJ/ha), Gross end-use electricity (MJ/ha), CO_2 emissions (Tonne/ha), CO_2eq-emisisons from CH_4 (Tonne/ha) and CO_2eq-emisisons from NO_2 (Tonne/ha) are then applied to the respective municipalities in addition to the percentages relating to agricultural surface area changes as stated above.

Agriculture	**2010**	**2012**	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Total Agricultural area (ha)	2,264,376	2,257,809	2,251,262	2,244,733	2,238,223	2,231,732	2,225,260	2,218,807
Change (%)		-0.29	-0.29	-0.29	-0.29	-0.29	-0.29	-0.29
Agricultural greenhouse cultivation (ha)	16,622	16,792	16,963	17,136	17,311	17,487	17,666	17,846
Change (%)		1.02	1.02	1.02	1.02	1.02	1.02	1.02
Other Agricultural area (ha)	2,247,754	2,241,011	2,234,288	2,227,585	2,220,902	2,214,239	2,207,597	2,200,974
Change (%)		-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30
Natural gas and Electricity (MJ/ha)	67,127	63,779	75,513	71,723	75,060	73,037	71,452	66,252
Change (%)		-4.99	18.40	-5.02	4.65	-2.69	-2.17	-7.28
Natural gas (MJ/ha)	59,177	54,478	61,299	57,913	60,762	58,251	56,623	50,027
Change (%)		-7.94	12.52	-5.52	4.92	-4.13	-2.80	-11.65
Gross end-use electricity (MJ/ha)	7,949	9,301	14,214	13,810	14,297	14,786	14,829	16,224
Change (%)		17.01	52.82	-2.84	3.53	3.42	0.29	9.41
CO_2 emissions (Tonne)	3.53	3.10	3.55	3.12	3.57	3.14	3.15	2.70
Change (%)		-12.25	14.62	-12.25	14.62	-12.25	0.29	-14.04
CO_{2eq}-emisisons from CH_4 (Tonne)	3.97	3.99	4.44	4.01	4.47	4.48	4.49	4.06
Change (%)		0.29	11.43	-9.74	11.43	0.29	0.29	-9.74
CO_{2eq}-emisisons from NO_2 (Tonne)	3.97	3.54	3.11	3.12	3.13	3.14	3.15	3.15
Change (%)		-10.85	-12.25	0.29	0.29	0.29	0.29	0.29

Table XIX- Annual Changes in ‘Intended Policies' Projections of Areas, Gross End-use of Electricity, Gas and CO_{2eq} Emissions in the Agricultural Sector

Industry

Finally, with respect to the Industrial sector, the national average gross end-use of natural gas, electricity and energy usage for mining resources are calculated based on the data as provided by the ECN (Hekkenberg & Verdonk, 2014b). Herein it is assumed that their corresponding growth percentages are directly applicable to the industries of De Bilt and Utrecht with the exception of the energy usage related to the mining of resources which, as of 2012, is not applicable to Utrecht or De Bilt (i.e. 0 energy demand as derived out of KlimaatMonitor). As a consequence, that portion of CO_{2eq} emissions emitted as a result of mining activities is subtracted from the total CO2eq emissions. The results of which are presented in Table XX in conjunction with their respective change percentages.

Industry	**2010**	**2012**	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Natural gas (PJ)	426	416	422	427	432	432	443	464
Change (%)		-2.3%	1.4%	1.2%	1.2%	0.0%	2.5%	4.7%
Gross end-use electricity (PJ)	140	126	125	119	122	126	130	134
Change (%)		-10%	-0.8%	-4.8%	2.5%	3.3%	3.2%	3.1%
CO2eq emissions (Mtonne)	14.0	13.5	14.7	14.6	15.1	14.9	14.9	14.9
Change (%)		-3%	8%	-1%	3%	-1%	0%	0%

Table XX – 'Intended Policies' Projections of the Gross End-use of Electricity. Natural Gas and Energy Usage for Mining Resources in the Industrial Sector (Michiel Hekkenberg & Verdonk. 2014b)

Herein, it appears that the overall natural gas and electricity utilized within this sector remains fairly constant (i.e. total change <10%) which is also reflected in the associated CO_{2eq} emissions.

Renewable Energy

The most recent data (i.e. 2014) relating to municipal sustainable energy production as derived out of the KlimaatMonitor indicate that for De Bilt the sole manner of sustainable electricity production is through PV-panels. Renewable heat is produced through solar boilers and derived out of warm milk, charcoal burning and wooden stoves. With respect to Utrecht, PV-panels and biogas derived out of the municipal sewage system are the sole sources of renewable electricity while renewable heat is produced through solar boilers, derived out of warm milk, charcoal burning and wooden stoves. In the 'intended policies' pathway, it is assumed that no new forms of sustainable energy production are introduced into the municipalities so that, effectively, solely projections relating to the aforementioned options are set out.

Herein, the 'intended policies' pathway projections related to PV-panels are based on the national projections supplied by the ECN (Hekkenberg & Verdonk, 2014b) and presented in conjunction with the associated growth percentages in Table XXI. Herein, a substantial relative increase in electricity out of PV-panels and solar boilers is projected (i.e. approx. 249 times as much energy is produced through PV-panels in 2030 when compared to 2010; whereas the heat produced through solar boilers doubles in the same period). These percentages are then applied to the respective amounts of electricity and heat as produced in the municipalities.

'Intended Policies' Projections for PV	**2010**	**2012**	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Electricity out of PV-panels (PJ)	0.2	0.9	1.8	3.2	5.1	16.6	24.4	49.7
Change (%)	-	450	200	178	159	325	147	204
Energy out of Solar Boilers (PJ)	1.0	1.1	1.1	1.1	1.2	1.6	1.8	2.2
Change (%)	-	110	0	0	109	133	113	122

Table XXI - 'Intended Policies' Projections of the Gross End-use of Electricity as Supplied through PV-panels and Energy supplied through Solar Boilers (Hekkenberg & Verdonk, 2014b)

Regarding the remaining identified sustainable heat production options, the trends as dervied out of the KlimaatMonitor are extrapolated for both Municipalities since no trends are provided through the ECN (Hekkenberg & Verdonk, 2014b). The subsequent projections are presented in Table XXII.

'Intended Policies' Projections for Sustainable heat	**2010**	**2012**	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Utrecht								
Charcoal (TJ)	5.0	5.1	5.2	5.3	5.3	5.7	5.9	6.3
Wooden Stoves (TJ)	20.0	21.2	23.4	24.0	25.0	30.2	33.4	40.6
Warm Milk (TJ)	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
De Bilt								
Charcoal (TJ)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Wooden Stoves (TJ)	54.8	55.2	55.7	58.4	58.9	64.5	67.9	75.8
Warm Milk (TJ)	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6

Table XXII - 'Intended Policies' Projections for Sustainable Heat Production through Charcoal Burning, Wooden Stoves and Heat Derived out of Warm Milk (Extrapolated data from 2014 on)

Finally, with respect to the municipality Utrecht, biogas is derived out of the municipal sewage system and converted into electricity. However, data is only available until 2014 and future projections are lacking. Therefore, it is assumed that the amount of biogas derived out of sewage is directly related to the amount of municipal inhabitants. Effectively, the projections concerning population growth (see section Table LVI in the appendix) are coupled with the electricity derived out of this biogas. It thereby functions as proxy-indicator of the growth in electricity produced out of biogas supplied through the municipal sewage system. This is presented in Table XXIII.

'Intended Policies' Projections Electricity out of Biogas	**2010**	**2012**	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Population of Utrecht	307,080	316,275	321,915	324,900	328,600	351,400	369,600	404,600
Change (%)	-	2.99	1.78	0.93	1.14	6.94	5.18	9.47
Electricity out of biogas supplied via municipal sewage system (TJ)	23.6	25.4	23.0	24.4	24.7	26.4	27.8	30.4

Table XXIII - 'Intended Policies' Projections of the Population of Utrecht and Electricity Derived Out of Biogas Supplied Through the Municipal Sewage System

3.7. MUNICIPAL MAXIMUM REALISABLE TECHNICAL POTENTIALS UNTIL 2030

The corresponding maximum realisable technical potentials are set out following a two-headed approach: focussing on those options relating to demand reductions through energy efficiency measures on the one hand, and renewable energy production on the other. Both these objects shall be provided for in terms of maximum technical implementation percentages relating to the respective sectors making up the energy-systems. With respect to the energy-efficiency potentials, the studies as provided by Harmelink et al., (2010) and multiple 'Sectoral Emission Reduction Potentials and Economic Costs for Climate Change' reports (CERPEC-CC) are predominantly utilized. The studies conducted by Benner & Warringa (2012) and Gerdes & van Zuijlen (2015) are applied to the sustainable energy production in the municipal energy systems whilst additional information is predominantly provided by Verkruijssen et al., (2014), Junginger et al., (2004) and Capros et al., (2010). Additional costs (relative to the 'IP' scenario) connected to these MRTPs are derived out of the same studies unless explicitly stated otherwise. Indirect cost, such as the cost of foregone demand from consumers, economy-wide costs, costs for welfare implications and non-financial costs are excluded.

3.7.1. MAXIMUM REALISABLE ENERGY-EFFICIENCY POTENTIALS

Maximum Realisable Energy-Efficiency Potential: Households

With respect to efficiency improvements relating to the required heat, the following projections are provided (Harmelink et al., 2010). On the national level, it is assumed that from 2012 on 250,000 households are renovated annually. This effectively corresponds to an annual renovation progress of 3.44% of the total national building stock (2012). This 3.44% is applied as the annual rate of renovation for De Bilt and Utrecht from 2015 until 2030. This implies that in the coming 15 years a total of 10,748 households are be renovated in De Bilt, which corresponds to 54.28% of the total households. For Utrecht, 104,312 households are renovated, corresponding to 50.17% of the total households. Renovation implies that *all* these renovated households require 15 kWh/m^2 of heat per year. As of 2012, the average household area of De Bilt is 182m^2 and 104m^2 for Utrecht (CBS, 2012) and this is assumed to remain constant. Renovated households in de Bilt are therefore assumed to require 2,730 kWh of heat per year, while the renovated households in Utrecht are assumed to require 1,560 kWh of heat per year. The additional costs related to renovation (floors, walls, roofs and windows; all with a lifetime of 30 years) are framed at €207,- per m^2 until 2020 and €212,- per m^2 for the period 2020-2030 (Bettgenhäuser et al. (2009). The total renovation costs in De Bilt are thus assumed at €37,674.- per household until 2020 and €38,584.- for 2020-2030. The renovation costs in Utrecht are assumed at €21,528.- per household until 2020 and €22,048.- for the period 2020-2030.

Additionally, it is expected that newly built households in the period 2015-2016 are built with an 'EnergiePrestatieCoëficiënt' (EPC) of 0.6 and for 2016-2020 an EPC of 0.4 is assumed. For 2020-2030 solely passive houses are assumed to be constructed, requiring 15 kWh/m^2 of heat annually (Bettgenhäuser et al., 2009). For De Bilt this implies an annual heat demand of 2,730 kWh per newly build household. For Utrecht an annual heat demand of 1,560 kWh per newly build household is assumed. The additional costs for building passive houses (related to standard building costs of €1,000.- per m^2 and a lifetime of 30 years) are framed at €65 per m^2 until 2020 and €20 per m^2 for the period 2020-2030 (Bettgenhäuser et al., 2009). The additional costs for building passive houses in De Bilt are thus assumed at €11,830.- per house until 2020 and €3,640.- per house for 2020-2030. With respect to Utrecht, €6,760.- per house is assumed until 2020 and €2,080.- per house for the period 2020-2030. It is assumed that these renovated and newly built service areas are equipped with heat-pumps (CoP > 4.5), combined with a heat/cold storage system that reduce the heat demand. This does, however, result in an increased electricity demand.

With respect to energy-efficiency developments connected to the electricity demand, these have been found to predominantly relate to improvements in household appliances (e.g. televisions, refrigerators) and lighting. It is assumed that, in 2050, the efficiency of lighting increased by 61%, stand-by efficiency by 82%, refrigerators by 76% and other appliances by 72%. In total this implies an annual energy reduction of 3% through improvements in electrical efficiencies (the increased electricity usage due to heat pumps with CoP>4.5 is included in this percentage) (Bettgenhäuser et al., 2009). This percentage corresponds exactly with the annual reduction percentages within the sector households as propounded by P. P. Capros et al. (2010). With respect to these electricity energy-efficiency measures the costs are assumed at -30€/Tonne CO_2 (Bettgenhäuser et al., 2009).

An overview hereof is presented in Table XXIV for De Bilt and Table XXV for Utrecht.

Households De Bilt	**2014**	**2015**	**2020**	**2023**	**2030**
Private households	19,363	19,619	20,384	20,639	21,402
Average household area (m^2)	182	182	182	182	182
Heat Demand					
Annual rate of renovation (%)	3.44				
Households renovated annually	-	675	701	710	736
Cumulative households renovated	-	675	4,141	6,263	11,351
Percentage of total building stock renovated (%)	-	3.44	20	30	53
Heat demand of renovated building stock (kWh/m^2)	15				
Heat demand of renovated building stock (kWh/household/year)	2,730				
Costs of total renovation per household (€/household)	37,674.-		38,584.-		
Newly build households annually	-	256	85	85	127
Cumulative newly built household	-	256	1,021	1,276	2,166
Percentage of newly build households	-	1	5	6	10
Cumulative newly built and renovated households	-	931	5,162	7,539	13,517
Percentage of cumulative newly built and renovated households (%)	-	4.7	25.3	36.5	63.2
Heat demand of newly built households (EPC until 2020; kWh/m^2 for 2020-2030)	0.6	0.6	0.4	15	15
Additional costs for newly build passive houses (€/household)	11,830.-		3,640.-		
Electricity Demand					
Overall annual energy demand reduction through improvements in electrical energy-efficiencies of lighting and appliances (%)	3				
Costs associated with electrical energy-efficiency improvements (€/Tonne CO_{2eq})	-30.-				

Table XXIV – 'MRTP' Energy Efficiency Households De Bilt: Key Figures

Households Utrecht	**2014**	**2015**	**2020**	**2023**	**2030**
Private households	169,505	171,742	178,440	179,927	187,356
Average household area (m^2)	104	104	104	104	104
Heat Demand					
Annual rate of renovation (%)	3.44				
Households renovated annually	-	5,907	6,138	6,215	6,445
Cumulative households renovated	-	5,907	41,970	60,538	104,964
Percentage of total building stock renovated (%)	-	3.44	23.5	33.6	56
Heat demand of renovated building stock (kWh/m^2)	15				
Heat demand of renovated building stock (kWh/household/year)	1,560				
Costs of total renovation per household (€/household)	21,528.-		22,048.-		
Newly build households annually	-	2,237	1,339	744	955
Cumulative newly built household	-	2,237	11,430	13,660	20,345
Percentage of newly build households	-	1.45	6.40	7.59	11.3
Cumulative newly built and renovated households	-	8,144	53,400	74,198	125,309
Percentage of cumulative newly built and renovated households (%)	-	4.7	29.9	41.2	66,9
Heat demand of newly built households (EPC until 2020; kWh/m^2 for 2020-2030)	0.6	0.6	0.4	11.5	11.5
Additional costs for newly build passive houses (€/household)	6,760.-		2,080.-		
Electricity Demand					
Overall annual energy demand reduction through improvements in electrical energy-efficiencies of lighting and appliances (%)	3				
Costs associated with electrical energy-efficiency improvements (€/Tonne CO_{2eq})	-30.-				

Table XXV – 'MRTP' Energy Efficiency Households Utrecht: Key Figures

Maximum Realisable Energy-Efficiency Potential: Services

With respect to the service sector, the supply of data is limited. Due to similarities with the sector households, it is assumed that the service sector is subjected to similar relative energy demand reductions through energy-efficiency improvements (Harmelink et al., 2010). No distinction is made between these developments with respect to their application to either commercial or public services. Overviews are presented in Table XXVI for De Bilt and Table XXVII for Utrecht.

As of 2012, the total service area of De Bilt amounted to approximately 2,510,000m^2, of which commercial services constituted 1,010,000m^2 and the public services 1,500,000m^2 (CBS, 2015b). When the national growth rates related to this sector (Table XIV) are applied, the total service area of De Bilt increases to 2,548,041m^2 in 2014 and roughly 2,820,000 m^2 in 2030 (i.e. an 310,000m^2 increase from 2014). By that time, roughly 1,490,000m^2 of service area has been renovated into service areas requiring 10 kWh/m^2 of heat (Bettgenhäuser et al., 2009); implying an annual heat demand of roughly 14,900,000 kWh in 2020 and 28,200,000 kWh in 2030 for this renovated area. The costs associated with renovation (floors, walls, roof and windows, all with 30 years lifetime) are framed at €207,- per m^2 until 2020 and €212,- for the period 2020-3030 (Bettgenhäuser et al., 2009).

In correspondence with the sector households; new service areas constructed in 2015-2016 are assumed to have an EPC of 0.6 and for 2016-2020 an EPC of 0.4 is presumed. During 2020-2030 solely 'passive' service areas are constructed, with an assumed heat requirement of 10 kWh/m^2 (Bettgenhäuser et al., 2009). Approximately 276,000 m^2 of new service area has been built, effectively requiring roughly 2,760,000 kWh of heat. The additional building-costs (related to standard building costs of €1,000.- per m^2 and a lifetime of 30 years) are framed at €20 per m^2 for the entire period studied (Bettgenhäuser et al., 2009).

It is assumed that these renovated and newly built service areas are equipped with heat-pumps (CoP > 4.5), combined with a heat/cold storage system that reduce the heat demand. This does, however, result in an increased electricity demand. This has been embodied with respect to the energy-efficiency developments connected to the electricity demand (Bettgenhäuser et al., 2009), and are assumed similar to those as presented in the sector households. In total they imply an annual energy reduction of 3% through improvements in electrical efficiencies (including the heat pumps). With respect to these electricity energy-efficiency measures the costs are assumed at -30€/Tonne CO_2 (Bettgenhäuser et al., 2009).

An overview hereof is presented in Table XXVI.

As of 2012, the total service area of Utrecht amounted to approximately 16,100,000m^2, of which commercial services constituted 11,800,000m^2 and the public services 4,300,000m^2 (CBS, 2015b). When the national growth rates related to this sector (Table XIV) are applied, the total service area of Utrecht increases to 16,344,010m^2 in 2014 and roughly 18,112,338m^2 in 2030 (i.e. an 2,012,338m^2 increase from 2014). By that time, roughly 9,552,911m^2 of service area has been renovated into service areas requiring 10 kWh/m^2 of heat (Bettgenhäuser et al., 2009); implying an annual heat demand of 34,736,910 kWh in 2020 and 95,529,110 kWh in 2030 for this renovated area. The costs associated with renovation (floors, walls, roof and windows, all with 30 years lifetime) are framed at €207.- per m^2 until 2020 and €212.- per m^2 for the period 2020-3030 (Bettgenhäuser et al., 2009).

In correspondence with the sector households; new service areas constructed in 2015-2016 are assumed to have an EPC of 0.6 and for 2016-2020 an EPC of 0.4 is presumed. During 2020-2030 solely ‘passive’ service areas are constructed, with an assumed heat requirement of 10 kWh/m^2 (Bettgenhäuser et al., 2009). Approximately 1,770,000m^2 of new service area has been built, effectively requiring roughly 17,700,000 kWh of heat. The additional building-costs (related to standard building costs of €1,000.- per m^2 and a lifetime of 30 years) are framed at €20 per m^2 for the entire period studied (Bettgenhäuser et al., 2009).

With respect to energy-efficiency developments connected to the electricity demand, these are assumed similar to those as presented in the sector households. In total they imply an annual energy reduction of 3% through improvements in electrical efficiencies (the increased electricity usage due to heat pumps with CoP>4.5 is included in this percentage). With respect to these electricity energy-efficiency measures the costs are assumed at -30€/Tonne CO_2 (Bettgenhäuser et al., 2009).

An overview hereof is presented in Table XXVII.

Services De Bilt	**2014**	**2015**	**2020**	**2023**	**2030**
Total service area (m^2)	2,548,041	2,569,700	2,677,884	2,715,642	2,823,725
Total area commercial services (m^2)	1,025,307	1,034,023	1,077,555	1,092,748	1,136,240
Total area public services (m^2)	1,522,734	1,535,677	1,600,329	1,622,894	1,687,485
Heat Demand					
Annual rate of renovation (%)	3.44				
Service area renovated annually (m^2)	-	88,398	92,119	93,418	97,136
Cumulative service area renovated (m^2)	-	88,398	541,535	820,481	1,489,257
Percentage of total building stock renovated (%)	-	3.44	20.22	30.21	52.74
Heat demand of renovated service area (kWh/m^2)	10				
Total heat demand of cumulative renovated service area (kWh/year)	-	883,950	5,415,320	8,204,780	14,892,540
Cost of renovation service area (€/m^2)	207.-			212.-	
Newly built service area (m^2)	-	21,658	21,637	12,586	15,440
Cumulative newly built service area (m^2)	-	21,658	129,843	167,601	275,683
Heat demand of newly built service area (EPC until 2020; kWh/m^2 for 2020-2030)	0.6	0.6	0.4	10	10
Additional costs for newly build service areas (€/m^2)	20.-				
Cumulative newly built and renovated service area (m^2)	-	110,056	671,393	988,107	1,764,988
Percentage of cumulative newly built and renovated service area (%)	-	4.28	25.07	36.39	62.51
Electricity Demand					
Overall annual energy demand reduction through improvements in electrical energy-efficiencies of lighting and appliances (%)	3				
Costs associated with electrical energy-efficiency improvements (€/Tonne CO_{2eq})	-30.-				

Table XXVI – 'MRTP' Energy Efficiency Services De Bilt: Key Figures

Services Utrecht	**2014**	**2015**	**2020**	**2023**	**2030**
Total service area (m^2)	16,344,010	16,482,934	17,176,866	17,419,059	18,112,338
Total area commercial services (m^2)	11,978,840	12,080,660	12,589,256	12,766,764	13,274,881
Total area public services (m^2)	4,365,170	4,402,274	4,587,610	4,652,295	4,837,457
Heat Demand					
Annual rate of renovation (%)	3.44				
Service area renovated annually (m^2)	-	567,013	590,884	599,216	623,064
Cumulative service area renovated (m^2)	-	567,013	3,473,691	5,263,007	9,552,911
Percentage of total building stock renovated (%)	-	3.44	20.22	30.21	52.74
Heat demand of renovated service area (kWh/m^2)	10				
Total heat demand of cumulative renovated service area (kWh/year)	-	5,670,130	34,736,910	52,630,070	95,529,110
Cost of renovation service area (€/m^2)	207.-			212.-	
Newly built service area (m^2)	-	138,924	138,786	80,731	99,040
Cumulative newly built service area (m^2)	-	138,924	832,856	1,075,049	1,768,328
Heat demand of newly built service area (EPC until 2020; kWh/m^2 for 2020-2030)	0.6	0.6	0.4	11.5	1.5
Additional costs for newly build service areas (€/m^2)	20.-				
Cumulative newly built and renovated service area (m^2)	-	705,937	4,306,547	6,338,056	11,321,239
Percentage of cumulative newly built and renovated service area (%)	-	4.28	25.07	36.39	62.51
Electricity Demand					
Overall annual energy demand reduction through improvements in electrical energy-efficiencies of lighting and appliances (%)	3				
Costs associated with electrical energy-efficiency improvements (€/Tonne CO_{2eq})	-30.-				

Table XXVII – 'MRTP' Energy Efficiency Services Utrecht: Key Figures

Maximum Realisable Energy-Efficiency Potential: Agriculture

Regarding the maximum realisable potential for the agricultural, options relating to electricity and gas use in greenhouse cultivation have been identified based on Harmelink et al. (2010). Other agricultural practices are assumed not to require a large electricity and gas supply but are, however, assumed responsible for the largest part of agricultural GHG-emissions through their CH_4 and N_2O emissions. The study as provided by Bates et al. (2009) supplies the technical potentials relating to CH_4 and N_2O emission abatement (expressed in CO_{2eq}).

Regarding greenhouse cultivation, energy-efficiency measures have been found to revolve around an increase in isolation measures that reduce the demanded heat by 30%. The percentage of annual implementation hereof relative to the total greenhouse cultivation area is assumed the same as the renovations occurring in the sector households (i.e. 3.44% annually). Furthermore, it is assumed that new greenhouse cultivation strategies are employed, effectively reducing the total energy demand by 10% in 2050 and 5% in 2020, extrapolation leads to a reduced energy demand of 6.67% in 2030. It is, however, explicitly noted that the impact of these new cultivation strategies has not been properly studied yet.

Newly build greenhouses, including heat pumps and heat/cold storage, have been found to reduce the total energy demand by 61%. The annual growth within this sector is assumed to be made up completely of these newly build greenhouses. With respect to the maximum realisable energy-efficiency potential in terms of electricity use, this is determined to account for an annual electricity demand reduction of -3% for the period 2010-2030. This may be achieved through more efficient lighting (e.g. LEDs emitting light of certain frequencies only).

With respect to the agricultural practices not related to greenhouse cultivation, the identified energy-efficiency options predominantly relate to: precision farming (reducing N_2O from soils), centralized anaerobic digestion of manure (reducing N_2O and CH_4 emission that would otherwise occur from manure storage or application), improvement of lifetime and efficiency of livestock (long term management and use of genetic resources that reduces enteric CH_4 emissions) and addition of nitrification inhibitors to soils (reducing N_2O emissions from soils). A complete, more detailed, overview of these identified options is presented in Table LX in the Appendices. The maximum realisable potential associated with the aforementioned abatement options for reducing N_2O and CH_4 emissions is adapted from European projections and framed at reducing 25% of the aggregate CO_{2eq} emissions in 2030. It includes all identified abatement measures up to 20 €/tCO_{2eq} with corresponding costs assumed at €-308 per Tonne of CO_2 abated (Bates et al., 2009). This suggests that agriculture abatement measures focussing on N_2O and CH_4 reductions could play a substantial role in delivering abatements in the non-EUETS sectors.

A complete overview with regards to De Bilt is provided in Table XXVIII and Table XXX, whereas Table XXIX and Table XXXI are representative of Utrecht.

Greenhouse Cultivation: De Bilt	**2014**	**2015**	**2020**	**2023**	**2030**
Total Agricultural area (ha)	3,413	3,402	3,350	3,319	3,247
Agricultural greenhouse cultivation (ha)	6	6	6	6	6
Other Agricultural area (ha)	3,407	3,396	3,344	3,313	3,242
Heat Demand					
Annual rate of renovation (%)	3.44	3.44	3.44	3.44	3.44
Agricultural area renovated annually (ha)	0.2064	0.2064	0.2064	0.2064	0.2064
Cumulative agricultural area renovated (ha)	0.2064	0.4128	1.2384	1.8576	3.3024
Percentage of total agricultural area renovated (%)	-	3.44	20.64	30.96	55.04
Heat reduction through renovation (%)	30				
Agricultural area newly build annually (ha)	0	0	0	0	0
Cumulative newly built agricultural area (ha)	0	0	0	0	0
Percentage of total agricultural area newly built (%)	0	0	0	0	0
Energy reduction in newly build agricultural areas as compared to non-renovated agricultural area (%)	61				
Electricity Demand					
Overall annual electricity demand reduction through improvements in electrical energy-efficiencies of lighting and appliances (%)	3				
Costs associated with electrical energy-efficiency improvements (€/Tonne CO_{2eq})	-30.-				

Table XXVIII - MRTP Energy Efficiencies Greenhouses De Bilt: Key Figures

Greenhouse Cultivation: Utrecht	**2014**	**2015**	**2020**	**2023**	**2030**
Total Agricultural area (ha)	2,376	2,338	2,157	2,055	1,836
Agricultural greenhouse cultivation (ha)	8.09	7.27	3.83	2.78	1.32
Other Agricultural area (ha)	2,370	2,333	2,157	2,058	1,843
Heat Demand					
Annual rate of renovation (%)	3.44	3.44	3.44	3.44	3.44
Agricultural area renovated annually (ha)	0.25	0.22	0.13	0.09	0.05
Cumulative agricultural area renovated (ha)	0.25	0.47	1.30	1.62	2.07
Percentage of total agricultural area renovated (%)	-	3.83	30.50	54.84	100
Energy reduction through renovation (%)	30				
Agricultural area newly build annually (ha)	0	0	0	0	0
Cumulative newly built agricultural area (ha)	0	0	0	0	0
Percentage of total agricultural area newly built (%)	0	0	0	0	0
Energy reduction in newly build agricultural areas as compared to non-renovated agricultural area (%)	61				
Electricity Demand					
Overall energy demand reduction through improvements in electrical energy-efficiencies of lighting and appliances (%)	3				
Costs associated with electrical energy-efficiency improvements (€/Tonne CO_{2eq})	-30.-				

Table XXIX - MRTP Energy Efficiencies Greenhouses Utrecht: Key FIgures

Agricultural CH_4 and N_2O: De Bilt	**2014**	**2015**	**2020**	**2023**	**2030**
Total Agricultural area (ha)	3,413	3,402	3,350	3,319	3,247
Agricultural greenhouse cultivation (ha)	6	6	6	6	6
Other Agricultural area (ha)	3,407	3,396	3,344	3,313	3,242
GHG Emissions					
Overall CO_{2eq} emissions through CH_4 (tonne)	13,578	15,136	15,169	15,203	13,747
Overall CO_{2eq} emissions through N_2O (tonne)	8,950	8,978	9,007	9,036	9,036
Total CO_{2eq} emissions through CH_4 and N_2O(tonne)	22,528	24,114	24,177	24,239	22,783
Total cumulative CO_{2eq} reduction percentage in 2030 (%)	25%				
Total cumulative CO_{2eq} reduction (linear interpolation) (tonne)	0	1,926	22,284	4,772	5,696
Costs associated with abatement options (€/Tonne CO_{2eq})	-308				
Total costs associated with abatement options (€)	-1,754,368				
Total remaining cumulative CO_{2eq} reduction (linear interpolation) (tonne)	22,528	22,188	20,488	19,467	17,087

Table XXX - MRTP Energy Efficiencies CH4 and N20 De Bilt: Key Figures

Agricultural CH_4 and N_2O: Utrecht	**2014**	**2015**	**2020**	**2023**	**2030**
Total Agricultural area (ha)	2,376	2,338	2,157	2,055	1,836
Agricultural greenhouse cultivation (ha)	8.09	7.27	3.83	2.78	1.32
Other Agricultural area (ha)	2,370	2,333	2,157	2,058	1,843
GHG Emissions					
Overall CO_{2eq} emissions through CH_4 (tonne)	6,715	7,485	7,502	7,519	6,799
Overall CO_{2eq} emissions through N_2O (tonne)	4,405	4,419	4,433	4,447	4,447
Total CO_{2eq} emissions through CH_4 and N_2O(tonne)	11,120	11,904	11,935	11,966	11,246
Total cumulative CO_{2eq} reduction percentage in 2030 (%)	25%				
Total cumulative CO_{2eq} reduction (linear interpolation) (tonne)	0	237	1,187	1,912	2,812
Costs associated with abatement options (€/Tonne CO_{2eq})	-308				
Total costs associated with abatement options (€)	-866,096				
Total remaining cumulative CO_{2eq} reduction (linear interpolation) (tonne)	11,120	11,667	10,748	10,054	8,434

Table XXXI - MRTP Energy Efficiencies CH4 and N2O Utrecht: Key Figures

Maximum Realisable Energy-Efficiency Potential: Transport

The options are identified based on (Leduc & Blomen, 2009) which heavily builds on (Smokers et al., 2006). Options relating to CNG, LPG and the Bus fleet have not been considered. Other options (e.g. H_2 fuel cells) might be available but at the time of this study, are deemed to complex and costly with very limited market penetrations. Additional costs refer to additional manufacturer costs required to produce a vehicle and are assumed constant over time. For electric cars and hybrids, however, a progress ratio of 0.83 was assumed; indicating that when the production volume doubles, production costs decrease with 17%

Regarding the maximum realisable energy-efficiency potential in the sector transport (i.e. mobility), the two predominant routes relate to increasing the efficiency of conventional internal combustion engines (ICE) vehicles on the one hand, and the introduction of non-conventional modes of automobile transportation on the other. With regard to the former, these developments relate to increasing engine efficiencies, minimizing driving shaft loses, lowering air and rolling resistances and a lowering of the weight. Regarding the latter, non-conventional modes of automobile transportation are defined as: hybrids, electrical vehicles and fuel cell vehicles.

With respect to drag reductions through improvements in aerodynamic improvements, as a rough estimation, fuel consumption can be reduced between 1% and 4% until 2030. Herein, a 1.5% reduction is assumed (this is however highly dependent on driving conditions). Estimated additional costs vary between €0.- to €105.-. An average additional cost of €75.- for the 1.5% fuel consumption regardless of vehicle type is assumed while market penetration hereof is assumed at 100% in 2030 (vehicles have an assumed lifetime of 15 years).

Relating to drag reductions through improvements in rolling resistance (typically responsible for 15%-30% of fuel ICE-consumption; highly depending on driving conditions); it is assumed that 10% reduction in rolling resistance will result in 1%-2.5% fuel savings. Typically two options apply: low resistance tyres (LLRT) and a tyre pressure monitoring system (TPMS). Regarding the former, the replacement of certain quantities of carbon black with silica in the tyre's tread composition result in a rolling resistance reduction of up to 20%, effectively saving 2%-5% of fuel. Herein, an average reduction potential of 3% is assumed. Current market-penetration is assumed at 94% so that the remaining 6% of cars are equipped in the period 2015-2020 against an assumed average additional cost of €30.- (range of €20-€70). With respect to the latter, the use of TPMS implies a reduced rolling resistance through continual optimization of tyre-pressure. Such a system would contribute to a reduction potential of 3%-4%, and an potential of 2.5% is assumed. The penetration of TPMS is assumed at 48% in 2015, 88% in 2020 and 100% in 2030. Associated costs are framed between €40.- and €65.- depending on system-variety. However, since solely the more accurate and reliable 'direct' system is applied in the European Union so that an additional cost of €65.- per system is assumed.

Advanced powertrains and weight reductions improving energy-efficiency relate to several advanced technologies which are set out in more detail in Table LXI and Table LXII in the appendices. All measures are averaged out and assumed to be included in newly acquired vehicles (starting in 2010 with an average life time 15 years). It should be noted that these values are estimates and thus subjected to certain degrees of uncertainty, e.g. type of reference car considered. The following ranges of potentials and costs were obtained: Potential fuel and CO_2 reductions from average sized petrol cars are assumed at 24.1% (20.5%-35%) with corresponding additional costs framed at €1,548.- (€1,104 to €2,074); these reductions are assumed at 21.3% for average sized diesel cars against an average additional cost of €1,291.-

Furthermore, accounting for possible overlap between different energy-efficiency measures (e.g. electric cars, full hybrids) it is assumed that the penetration for the petrol fleet amounts to 2% in 2010, 41% in 2020 and 61% in 2030. For diesel these assumptions amount to 4% in 2010, 47% in 2020 and 67% in 2030.

A shift in the car fleet from conventional ICE cars to (plug-in) hybrid electric vehicles (PHEVs and HEVs) can further improve the energy-efficiency and reduce the CO_2 emissions in the transport sector. Herein it is assumed that both petrol and diesel hybrid vehicles have led to an energy reduction of 25% in the period 2010-2015, and will further increase to 40% by 2030. The associated additional costs (which reduce through technological developments and economies of scale) and market penetration rates are presented in Table XXXII.

Penetration Rates and Costs associated with hybrids	**2010**	**2015**	**2020**	**2025**	**2030**
Hybrid Petrol					
% of total fleet	1%	6%	10%	15%	20%
Additional costs (€/unit)	3,500	2,147	1,842	1,624	1,480
Hybrid Diesel					
% of total fleet	0%	1%	5%	10%	14%
Additional costs (€/unit)	3,500	3,500	2,206	1,800	1,626
Average Hybrid					
% of total fleet	0.5%	3.5%	7.5%	12.5%	17%
Additional costs (€/unit)	3,500	2,824	2,024	1,712	1,553

Table XXXII - Penetration Rated and Associated Costs of Petrol and Diesel Hybrid Vehicles (Leduc & Blomen, 2009)

Behavioural change can significantly affect fuel consumption and associated GHG emissions through so-called “eco-driving-styles”. Herein, the driver is trained to: Shift from a higher gear below 2500 rpm (for petrol, 2000rpm for diesel), maintain a steady speed in the highest gear possible, look ahead and anticipate traffic flow, minimizing abrupt accelerating or breaking, etc. Short-term effect may reduce 5%-25% of fuel depending on individual driving style. Long-term effects, however, decrease significantly over time so that in this study an estimated achievable long term (i.e. >1year) effect is assumed at 3% (2%-3.5%, lasting for 25 years). An additional 1.5% fuel reduction can be achieve through the installation of “intelligent” gear shift indicator systems (GSI), which is perceived a valuable driver assistance system. The market penetration of eco-driving is assumed at 20% in 2020, 38% in 2025 and 70% in 2030 of the total car fleet. The costs of eco-driving lessons are assumed constant at €100.- whereas the additional manufacture cost of GSI is framed at €15; resulting in a 4.5% fuel reduction against a total cost of €115.-

The options relating to biofuels (biodiesel and bioethanol) are fraud with uncertainties. It is dependent on a multitude of complex interactions influencing the uptake of different kinds of biofuels (conventional or advanced), oil prices and the type of policy support (e.g. tax exemptions); thereby rendering assumptions relating to the share of biofuel in the transport sector inherently uncertain. The associated well-to-wheel CO_2 emissions are highly dependent on upstream emissions (generated during biofuel production; the tank-to-wheel emissions are deemed carbon neutral) and an analysis of this lies outside of the current scope. Therefore, it is assumed that substituting fossil fuels by biofuels reduces the well-to-wheel GMG emissions by 57%. The associated additional cost are assumed at €8.35 per substituted GJ of fossil fuel. Market penetration is equally uncertain and assumed here at 12% in 2020 and 14% in 2030.

With respect to energy-efficiency improvements through the introduction of hydrogen (H_2) fuel cell cars, it is assumed that in the short term, natural gas is the only viable source of large-scale hydrogen production that could potentially reduce GHG-emissions albeit at higher costs. It is not guaranteed that economies of scale will significantly reduce these costs due to the complex and fairly immature technologies and the possibility of biofuels being produced in high volumes against reasonable costs. Correspondingly, no set trends nor market dynamics are clearly defined and, additionally, car manufactures focus more on hybrid and electrical technologies. The penetration of H_2-fuelled cars is likely to gradually increase between 2010 and 2050. However, market penetration will probably not take place before 2020. The overall market penetration and associated costs are 1% in 2020 with an additional costs of €32,500.-; 3% in 2025 against €20,000.- and 5% in 2030 against €7,500.-. In light of the low degree of implementation, high additional costs, highly uncertain upstream GHG-emissions and competition with the electric car (which has a much larger assumed implementation potential), the H_2 fuel cell car energy-efficiency potential is not included

Finally, energy-efficiency improvements relating to the market penetration of electric cars is taken into account. Electric cars can substantially reduce CO2 emissions (especially when the electricity is generated sustainably). Furthermore, electricity costs are considerably less than the costs of conventional fuels. It is assumed that an electric car requires 79.1% less energy (i.e. 0.16 kWh/km) than an average conventional ICE vehicle. In order to obtain the associated GHG emissions this needs to be converted utilizing the projected electricity grid emission factors. Market penetration rates are assumed at 4% in 2020 and 20% in 2030 of the total car fleet. The associated additional costs (utilizing progress rates of 0.83 for technology learning) are framed at €10,667.- in 2020, €8,336.- in 2025 and €6,527.- in 2030.

A complete overview is presented in Table XXIII.

<table>
<tr><th><i>Energy efficiency options</i></th><th>Fuel and CO_{2eq} Reduction potential per vehicle (%)</th><th>Average additional costs (€/vehicle)</th><th>Penetration rates total vehicle fleet (%)</th></tr>
<tr><td><i>Improved aerodynamics</i></td><td>1.5%</td><td>75.-</td><td>100% by 2030</td></tr>
<tr><td><i>LRRT</i></td><td>3%</td><td>30.-</td><td>95% currently, remaining 6% in 2015-2020</td></tr>
<tr><td><i>TPMS</i></td><td>2.5%</td><td>65.-</td><td>48% (2015), 88%(2020), 100% (2030)</td></tr>
<tr><td><i>Advanced powertrains and weight reductions</i></td><td>22.7% (Average)</td><td>1,419.5 (Average)</td><td>41%(2020),
61%(2030)</td></tr>
<tr><td><i>Full hybrid cars</i></td><td>25% (2010-2015),
40% (2030)</td><td colspan="2"><table>
<tr><th></th><th>2010</th><th>2015</th><th>2020</th><th>2025</th><th>2030</th></tr>
<tr><td colspan="6"><i>Average Hybrid</i></td></tr>
<tr><td><i>% of total fleet</i></td><td>0.5%</td><td>3.5%</td><td>7.5%</td><td>12.5%</td><td>17%</td></tr>
<tr><td><i>Additional costs (€/unit)</i></td><td>3500</td><td>2824</td><td>2024</td><td>1712</td><td>1553</td></tr>
</table></td></tr>
<tr><td><i>Eco-driving</i></td><td>4.5%</td><td>115.-</td><td>20% (2020), 38% (2025), 70% (2030)</td></tr>
<tr><td><i>Biofuels</i></td><td>57%</td><td>8.35 per substituted GJ of fossil fuels</td><td>12% (2020), 14% (2030)</td></tr>
<tr><td><i>Electric cars</i></td><td>79.1% less energy required; GHG emitted based on projected electricity grid emission factors</td><td>10,667.- (2020)
8,336.- (2025)
6,527.- (2030)</td><td>4% (2020),
20% (2030)</td></tr>
</table>

Table XXXIII - Identified Energy Efficiency Options in Transport Sector – Predominantly based on Leduc & Blomen (2009)

Maximum Realisable Energy-Efficiency Potential: Industry & Energy

An overview of identified technical measures for the European industry sector forms the basis for the identified municipal maximum realisable energy-efficiency potential when applied to the respective municipal energy-systems. Since the KlimaatMonitor does not supply a detailed overview of the constituting individual industrial companies, no assumptions are made with respect to detailed specific energy-efficiency measures relating to specific industries since it is not attained whether or not these specific measures are applicable to De Bilt or Utrecht.

For these reasons, two distinct abatement measures are established: replacing the old industrial building stock with new (more energy-efficient) capacity on the one hand, and different cross cutting measures that are applicable to all industrial sectors on the other (Overgaag et al., 2009). The most detailed level of industrial sectors as provided by the KlimaatMonitor is: Industry (SBI C), Mining (SBI B), Production and distribution of electricity, gas, steam and cooled air (SBI D), Construction (SBI F) and Waste disposal. Measures refer either to further implementation of technologies that are already partly included in the baseline, or application of new abatement techniques that are available on the market today.

Regarding energy-efficiency potentials relating to the replacement of the existing industrial building stock utilizing the Best Available Technology (BAT) available, lifetimes of 25 years are assumed. As a consequence 4% of the existing building stock is replaced annually. Additionally, increased production is supplied entirely through newly build industrial building stock, adhering to the same BAT. The new industrial stock is assumed to perform at a 20%-40% improved energy-efficiency (assumed at 30%) when compared to the performance of 2008. From a legal (IPPC Directive) and long-term cost perspective, an alternative (i.e. an average performing and cheaper technology), is assumed not to be available; implying no (€0.-) additional costs involved in the implementation of new production capacity.

Furthermore, typically, a range of energy efficiency measures exist that has the potential to be implemented in all industrial sectors. These measures are dubbed 'cross cutting measures' and are derived out of the Industrial Assessment Centres (IAC) database from Rutgers University. They have been converted by SERPEC and three types of cross-cutting measures were distinguished: measures reducing electricity use, measures reducing fuel use and measures reducing both fuel and electricity demand. On average, these measures save some 10% energy per sector against an average cost of €15.- per GJ saved. Similar to the industrial stock turn-over, it is assumed that by 2020, 60% of industrial sectors have implemented these measures and 100% by 2030 (both compared to 2008). An over view of these findings is presented in Table XXXIV.

Industrial Energy-efficiency Option	**Energy reduction (%)**	**Associated additional costs €/GJ$_{saved}$**	**Implementation (%)**
Industrial building stock turnover	30%	0	60% (2020)
Cross cutting measures	10%	15.-	100% (2030)

Table XXXIV - Identified Industrial Energy-efficiency Options; adapted from Overgaag et al. (2009)

3.7.2. MAXIMUM REALISABLE POTENTIAL OF SUSTAINABLE ENERGY PRODUCTION

The maximum realisable potential relating to municipal sustainable energy production is predominantly based on the studies supplied by Benner & Warringa (2012) and Oude Lohuis et al. (2015) with respect to Utrecht and Verkruijssen et al. (2014) with respect to De Bilt. These are supplemented with data supplied by Gerdes & van Zuijlen (2015) and other sources cited throughout the text.

For bot municipalities, the following options revolving around sustainable energy production have been identified: Large scale wind turbines, urban windmills, photovoltaic systems (PV-cells), Solar thermal systems (solar collectors), Biomass (biogas). These are treaded individually and per municipality in the succeeding chapters.

Sustainable Energy Production: Large Scale Wind Turbines

According to the report by Benner & Warringa (2012), the municipality of Utrecht has the potential to produce 78 MW of electricity through the implementation of large scale wind turbines within the municipal borders. It is assumed that this is produced through turbines rated at 2.4 MW requiring around 33 of such turbines. These wind turbines are assumed to produce 174,240 MWh/year with a load factor of 2,200 hours year and wind speed of 6.5 m/s at 100 meter. This corresponds to a sustainable energy production of around 627 TJ per year.

Herein, it is assumed that these turbines can solely be placed outside of a buffer of a minimum of 400 meter outside of the building environment and can be installed without having any detrimental effect on anthropological (i.e. roads, railways, etc.) and main ecological structures. The turbines require a minimum interval of 500 meter between them. Current large scale land wind turbines can be rated to as much as 6-7.5MW but since these are relatively expensive and impractically large, they are not deemed suitable for municipal implementation (Gerdes & van Zuijlen, 2015).

With respect to De Bilt, the maximum realisable potential is based on a comparison between Utrecht and De Bilt in terms of municipal surface area. The limitations as described above are assumed to hold while other potentially limiting or stimulating effect have been disregarded. Based on the total municipal area of Utrecht (9,921 hectare) and De Bilt (6,713 hectare) (CBS, 2015a), the sustainable energy produced is effectively 67.7% that of the municipality of Utrecht.

The key figures assumed for large scale wind turbines in De Bilt are thus as follows: 50.7 MW of energy can be produced requiring 22 turbines rated at 2.4 MW (average wind speed is 6.5m/s at 100m); corresponding to 166,296 MWh/year (load factor of 2,200) or roughly 599 TJ per year (Gerdes & van Zuijlen, 2015; Cleijne et al., 2010).

The associated costs are based on the ECN ‘Eindadvies basisbedragen SDE+2015’ and specifically the chapter ‘Wind op land <7.0m/s. A lifetime of 15 years is assumed and for the period 2015-2030 a price drop of 18% is expected based on the RESolve-E model provided by the ECN (Gerdes & van Zuijlen, 2015). The maintenance costs are assumed constant in time. The overall findings are presented in Table XXXV and Table XXXVI. Additional studies are required in order to yield more detailed projections supplementing these indicative results.

Potential of Large Scale Wind Turbines Utrecht	
Number of turbines	33
Rated power of turbine	2.4 MW
Installed power	78 MW
Wind speed (100 meter)	6.5 m/s
Load factor	2,200/8,760
Annual electricity produced	174,240 MWh 627 TJ
Potential of Large Scale Wind Turbines De Bilt	
Number of turbines	22
Rated power of turbine	2.4 MW
Installed power	50.7 MW
Wind speed (100 meter)	6.5 m/s
Load factor	2,200/8,760
Annual electricity produced	166,296 MWh 599 TJ

Table XXXV - Maximum Realisable Potential of Large Scale Wind Turbines in Utrecht & De Bilt

Costs Associated With Large Scale Wind Turbines		
Type of Costs	**2015**	**2030**
Investment costs (€/kW)	1,350.-	1,100.-
Fixed maintenance costs (€/kW)	15.3	15.3
Variable Maintenance costs (€/kW)	0.0143	0.0143
Costs per kWh (€/kWh)	0.098	0.086

Table XXXVI - Costs Associated With Large Scale Wind Turbines. Based on Gerdes & van Zuijlen (2015) *and* Lensink & van Zuijlen (2014)

Sustainable Energy Production: Urban Windmills

According to the report by Benner & Warringa (2012), in 2030 the municipality of Utrecht has the maximum realisable potential to produce roughly 75 TJ of electricity annually through the implementation of small scale urban windmills within the municipal borders. At an assumed annual electricity production of 1,500 kWh (or 0.0054TJ) per urban windmill at 3.5 m/s wind speeds (Gerdes & van Zuijlen, 2015), this requires the instalment of 13889 urban windmills. Herein, the load factor is assumed at 600/8,760 and the rated power of urban wind turbines is assumed at an average of 2.5 kW per turbine.

With respect to De Bilt, the maximum realisable potential is based on a comparison between Utrecht and De Bilt in terms of municipal surface area. The limitations as described above are assumed to hold while other potentially limiting or stimulating effect have been disregarded. Herein, it is assumed that 67.7% of the amount of urban windmills installed in Utrecht is installed in De Bilt, amounting to 9,403 windmills. At the rated power of 2.5 kW, 600/8,760 load factor and 3.5 m/s wind speed, this amount to a total annual sustainable electricity production of roughly 51 TJ through urban windmills within the municipal borders.

When compared to the large scale wind turbines these are fairly insubstantial amounts of sustainable electricity (approximately ten times lower). Additionally, the investment costs (per kW) are roughly four times as large, rendering it a less attractive option than large scale wind turbines in terms of costs and electricity produced. These associated costs assume the same price drop of 18% with respect to large scale wind turbines as provided through the RESolve-E model provided by the ECN (Gerdes & van Zuijlen, 2015). Potentials and costs are presented in Table XXXVII and Table XXXVIII. Additional studies are required in order to yield more detailed projections supplementing these indicative results.

Potential of Urban Windmills Utrecht	
Number of turbines	13,889
Rated power per turbine	2.5 kW
Installed power	34.7 MW
Windspeed	3.5 m/s
Load factor	600/8,760
Annual electricity produced	75 TJ
Potential of Urban Windmills De Bilt	
Number of turbines	9,403
Rated power of turbine	2.5
Installed power	23.5 MW
Windspeed	3.5 m/s
Load factor	600/8,760
Annual electricity produced	51 TJ

Table XXXVII - Maximum Realisable Potential of Urban Windmills in Utrecht & De Bilt

Costs Associated With Urban Windmills		
Type of Costs	**2015**	**2030**
Ivestment costs (€/kW)	5,182.-	4,250.-
Fixed maintenance costs (€/kW)	15.3	15.3
Variable Maintenance costs (€/kW)	0.0143	0.0143
Costs per kWh (€/kWh)	1.09	0.89

Table XXXVIII - Costs Associated With Urban Windmills. Based on (Gerdes & van Zuijlen, 2015)

Sustainable Energy Production: Photovoltaic Systems (PV-cells)

The municipality of Utrecht has a significant maximum realisable potential related to electricity production through the implementation of urban photovoltaic systems within the municipal borders. The total suitable urban area for photovoltaics in 2030 is demarcated according to Benner & Warringa (2012). Herein, the average performance is assumed at 850 kWh/kWp/year and remains constant over time. The associated power per surface area (kWp/m^2) is assumed at 0.13 kWp/m^2 for households and services (lifetime 15 years) while a value of 0.15 kWp/m^2 is assumed for industry (lifetime 25 years) (Gerdes & van Zuijlen, 2015). An overview hereof is presented in Table XXXIX. The total amount of electricity produced annually amounts to 112,611,790 kWh which corresponds to roughly 405 TJ/year.

Sector	**Total surface area (m^2)**	**Percentage deemed suitable (%)**	**Suitable Surface Area (m^2)**	**Percentage applied (%)**	**Performance (kWh/kWp)**	**Power per surface area (kWp/m^2)**	**Electricity production (kWh/year)**
Households	21,621,600	8.6	1,860,953	43	850	0.13	88,423,182
Services	18,112,338	2.3	422,589	15	850	0.13	7,004,413
Industry	9,900,000	13.6	1,347,780	10	850	0.15	17,184,195
Total	49,633,938	7.3	3,631,321				112,611,790

Table XXXIX - Maximum Realisable Potential for Urban PV-cells in the Municipality Utrecht in 2030. Based on: Benner & Warringa (2012) *and* Gerdes & van Zuijlen (2015)

This serves as basis for the maximum realisable potential related to electricity production in De Bilt through urban PV-systems within the municipal borders. All assumptions remain fixed with the exception of the respective total and suitable surface areas for households, services and industry. An overview hereof is presented in Table XL. The annual total amount of electricity produced in this fashion amounts to 17,015,655 kWh, which corresponds to roughly 61 TJ/year. The suitable household surface area for the Bilt in 2030 is estimated based on the projected total household surface area in 2030 (see section 3.7.1), multiplied by the percentage of suitable household surface areas as established with respect to Utrecht (i.e. 8.6%). The total service surface area for De Bilt in 2030 and the total industrial surface area for 2030 has also been estimated in section 3.7.1.

Sector	**Total surface area (m^2)**	**Percentage deemed suitable (%)**	**Suitable Surface Area (m^2)**	**Percentage applied (%)**	**Performance (kWh/kWp)**	**Power per surface area (kWp/m^2)**	**Electricity production (kWh/year)**
Households	3,603,600	8.6	309,910	43	850	0.13	14,725,374
Services	2,823,725	2.3	64,946	15	850	0.13	1,076,480
Industry	700,000	13.6	95,200	10	850	0.15	1,213,800
Total	7,127,325	7.3	470,056				17,015,655

Table XL - Maximum Realisable Potential for Urban PV-cells in the Municipality De Bilt in 2030; based on Table XXXIX

Additionally, solar field systems can be developed in the more rural areas of Utrecht and De Bilt. However with respect to Utrecht the total surface area available for this is fairly limited. According to CBS (2015c), out of the total area of 9,433 hectares, 2,713 hectares is non-urban and of this part merely 170 hectares is allocated as forests and open natural area (the other 2,543 hectare is agricultural area and disregarded due to potential trade-offs in electricity and agricultural production). With respect to De Bilt, however, this amounts to 1,581 hectares which potentially greatly increases the potential for PV-field. Based on Gerdes & van Zuijlen (2015) it is assumed that 70% of these areas (which are assumed to remain constant) can be realised as solar field systems. When applied, the municipality of Utrecht can sustainably produce 546 TJ/year in this manner (a value significantly higher than the 405TJ/year that is produced through PV systems in urban areas); whereas De Bilt can produce 5,080 TJ/year (which is substantially higher than through urban PV systems in De Bilt do to the relatively large available rural surface area). An overview hereof is presented in Table XLI. Additional studies are required in order to yield more detailed projections supplementing these indicative results. It is explicitly noted that for this large are of De Bilt to be converted to solar PV fields will require drastic land-use changes (e.g. cutting down forests) which may heavy encounter resistance from inhabitants. This is expanded upon in the discussion.

Solar PV Field systems	
Utrecht	
Available area (ha)	170
Area realised as PV field system (%)	70
Solar irradiance (kWh/kWp/year)	850
Power per surface area PV (kWp/m^2)	0.15
Total production (MWh/year)	151,725
Total production (TJ/year)	546
De Bilt	
Available area (ha)	1,581
Area realised as PV field system (%)	70
Solar irradiance (kWh/kWp/year)	850
Power per surface area PV (kWp/m^2)	0.15
Total production (MWh/year)	1,411,053
Total production (TJ/year)	5,080

Table XLI - Maximum Realisable Potential for Rural PV Field Systems in the Municipalities De Bilt and Utrecht in 2030

The associated costs are derived out of ECN models (assuming an 18% price drop, based on progress ratios of 0.82) and presented in Table XLII and Table XLIII.

Costs Associated With Household PV-systems		
Costs	**2015**	**2030**
Investment costs (€/kW_p)	1,488	1,220
Replacement of inverter (1 time) (€/kW_p)	204	167
Maintenance costs (€/kW_p)	20	16
Costs per kWh (€/kWh)	0.221	0.181
Costs per T (€/TJ)	60,976	50,000

Table XLII - Costs Associated With Household PV-systems in 2015 and 2030 (Gerdes & van Zuijlen, 2015)

Costs Associated With Service/Industrial/Field PV-systems		
Costs	**2015**	**2030**
Investment costs (€/kW_p)	841	690
Replacement of inverter (1 time) (€/kW_p)	138	113
Maintenance costs (€/kW_p)	11	9
Costs per kWh (€/kWh)	0.129	0.106
Costs per T (€/TJ)	35,366	29,000

Table XLIII - Cost Associated With Service/Industrial/Field PV-systems in 2015 and 2030 (Gerdes & van Zuijlen, 2015)

Sustainable Energy Production: Solar Thermal

The maximum realisable technical potential related to solar thermal energy (i.e. heat) production within the borders of the municipality Utrecht is demarcated according to Benner & Warringa (2012). Herein, it is estimated that 27,000 solar boilers are installed in the upcoming 15 years. The solar boiler considered here is solely applied to households with suitable rooftops, requiring 2.5m^2 per unit, including the associated thermal storage container. It is assumed that all thermal energy is utilized within the household (or discarded). A lifetime of 15 years is assumed with an associated average thermal capacity of 400 kWh_{the}/m^2/year; due to substantial uncertainties relating to the expected development costs, the 2015 costs provided by the ECN are assumed constant (Gerdes & van Zuijlen, 2015). Penetration rates are assumed at 50% in 2020 and 100% in 2030. Potentials (2030) and costs are provided in Table XLIV and Table XLV.

The estimated number of solar boilers installed in De Bilt is based on the relative difference in household surface area (2030 estimations) between Utrecht (207,900 households of 104m^2) and De Bilt (19,800 households of 182m^2) as set out in chapter 3.7.1. When each solar boiler system requires 2.5m^2 this implies that 0.312% of the total household surface area of Utrecht will have solar boilers installed. Juxtaposing this percentage on the total household surface area of De Bilt implies the installation of 4,497 solar boilers in 2030 in the municipality De Bilt. Other characteristics are assumed constant.

It is noted that due to the more rural characteristics of the building environment in De Bilt, the overall suitability of household rooftops for solar thermal boilers is assumed to be (at least) the same as that of Utrecht (which has a more urban building environment, implying larger height differences amongst buildings and, as a general rule, more shading). Additional studies are required in order to yield more detailed projections supplementing these indicative results.

Due to the sole application of solar boilers to households, the maximum realisable potential for Utrecht is roughly six times as large as that of De Bilt; corresponding to the relative difference in household surface area between the two municipalities.

Solar Thermal Systems (Solar Boilers) 2030	
Utrecht	
Estimated number of solar boilers installed	27,000
Surface area required per solar boiler (m^2)	2.5
Total area required (m^2)	67,500
Thermal capacity (kWh_{the}/m^2/year)	400
Total thermal energy produced (kWh_{the}/year)	27,000,000
Total production (TJ/year)	97.2
De Bilt	
Estimated number of solar boilers installed	4,497
Surface area required per solar boiler (m^2)	2.5
Total area required (m^2)	11,243
Thermal capacity (kWh_{the}/m^2/year)	400
Total thermal energy produced (kWh_{the}/year)	4,497,200
Total production (TJ/year)	16.2

Table XLIV - Maximum Realisable Potential for Solar Thermal Systems (Solar Boilers) in the Municipalities Utrecht and De Bilt in 2030

Costs Associated With Solar Thermal systems		
Type of Costs	**2015**	**2030**
Investment costs (€/kW$_{the}$)	700	700
Fixed Maintenance costs (€/kW$_{the}$)	5	5
Variable Maintenance costs (€/kW$_{the}$)	3.2	3.2
Costs per kWh (€/kWh$_{the}$)	0.137	0.137
Costs per T (€/TJ$_{the}$)	38,000.-	38,000.-

Table XLV - Costs associated with the 'MRTP' Solar Thermal Systems in 2015 and 2030 (Solar Boilers)

Sustainable Energy Production: Biomass

The maximum realisable technical potentials related to energy derived out of biomass (i.e. electricity and heat) within the borders of the municipalities, are demarcated according to the respective amounts of biomass waste generated and the associated biomass power plants in which electricity and heat is to be generated.

First-off, the type and amount of biomass waste that is collected is presented in Table XLVI as derived out of the KlimaatMonitor. Herein, AB wood is wood suitable for burning in biomass plants (C-wood is impregnated wood and is disregarded as potential fuel since this cannot be burned without highly adverse emissions). The data for 2013 is assumed constant until 2030 and this is multiplied by the projected number of inhabitants as presented in Table LVI of the appendix. The result of which are presented in Table XLVII. The associated energy contents are derived out of the ECN's SDE+2015 (Lensink & van Zuijlen, 2014) and amount to 7GJ/Tonne for organic waste and garden waste while amounting to 13GJ/Tonne for AB-wood waste.

De Bilt					
2014	41800	-	19000	-	2,20
2015	41600	-0,48	19100	0,53	2,18
2016	41500	-0,24	19200	0,52	2,16
2017	41300	-0,48	19300	0,52	2,14
2018	41100	-0,48	19300	0,00	2,13
2019	41000	-0,24	19400	0,52	2,11
2020	40900	-0,24	19500	0,52	2,10
2021	40800	-0,24	19600	0,51	2,08
2022	40600	-0,49	19600	0,00	2,07
2023	40600	0,00	19600	0,00	2,07
2024	40500	-0,25	19600	0,00	2,07
2025	40400	-0,25	19700	0,51	2,05
2026	40400	0,00	19700	0,00	2,05
2027	40400	0,00	19800	0,51	2,04
2028	40400	0,00	19800	0,00	2,04
2029	40200	-0,50	19800	0,00	2,03
2030	40200	0,00	19800	0,00	2,03

Type and Amount of Biomass Waste collected per Inhabitant	**2009**	**2010**	**2011**	**2012**	**2013**
Utrecht					
Isolated collected organic waste (kg/inhabitant)	28	28	29.7	31.6	31
Isolated collected garden waste (kg/inhabitant)	7	8	6.1	6.1	6.2
Isolated collected AB-wood waste (kg/inhabitant)	18.8	19	18.4	17.9	18.1
De Bilt					
Isolated collected organic waste (kg/inhabitant)	127	122	121.6	131.1	124.5
Isolated collected garden waste (kg/inhabitant)	40	28	28	31.2	27.2
Isolated collected AB-wood waste (kg/inhabitant)	22.4	24	25	28.6	29.6

Table XLVI - Type and Amount of Biomass Waste Collected per Inhabitant (Rijkswaterstaat Afvalmonitor, CO2MPAS, & NVRD, 2015)

Type and Amount of Biomass Waste collected	**2015**	**2030**	**(GJ/Tonne)**
Utrecht			
Isolated collected organic waste (KTonne)	10.4	12.5	7
Isolated collected garden waste (KTonne)	2.0	2.5	7
Isolated collected AB-wood waste KTonne)	5.9	7.3	13
De Bilt			
Isolated collected organic waste (KTonne)	5.4	5	7
Isolated collected garden waste (KTonne)	1.3	1.1	7
Isolated collected AB-wood waste (KTonne)	1.2	1.2	13

Table XLVII - Type and Amount of Biomass Waste Collected in 2015 and 2030 (Total)

The relevant characteristics of the associated biomass power plant are sketched-out by the municipality of Utrecht and are assumed at 60MW of heat and 20MW of electricity through co-generation. The specific type of biomass plant, however, is undefined (Kersemakers, 2013); resulting in large uncertainties related to the associated investment and maintenance costs of the plant. Data with respect to De Bilt is lacking and therefore the same assumptions as those relating to Utrecht are applied. As an average and frequently recurring indicator with respect to different available types of biomass plants, a load factor of 7,000 hours is assumed (Lensink & van Zuijlen, 2014) . Furthermore, an assumed plant rated at 60MW heat and 20MW electricity consumes 2,016,000 GJ annually which is approximately ten times the amount of biomass (in terms of GJ) that is collected in Utrecht, and over twenty times that which is collected in De Bilt. Therefore, it is assumed that these biomass plants derive the remainder of required biomass out of different sources outside of the municipalities whilst solely that part of the energy resulting from municipal biomass is fed back into that same municipality. This results in the data as provided in Table XLVIII.

Utrecht	
Organic Waste (GJ/year)	87,500
Garden Waste (GJ/year)	17,500
AB-wood Waste (GJ/year)	94,900
Total Available biomass potential (GJ/year)	199,900
Type of Biomass Plant	Unknown (criteria: cogeneration)
Electrical efficiency (%)	20
Thermal efficiency (%)	60
Electricity produced (MWh/year)	11,106 (40 TJ/year)
Heat produced (MWh/year)	33,317 (120 TJ/year)
De Bilt	
Organic Waste (GJ/year)	35,000
Garden Waste (GJ/year)	7,700
AB-wood Waste (GJ/year)	8,400
Total Available biomass potential (GJ/year)	51,100
Type of Biomass Plant	Unknown (criteria: cogeneration)
Electrical efficiency (%)	20
Thermal efficiency (%)	60
Electricity produced per year (MWh/year)	2,839 (10 TJ/year)
Heat produced per year (MWh/year)	8,516 (31 TJ/year)

Table XLVIII - Biomass Potential for Biomass Derived Out of Utrecht and De Bilt in 2030

4 RESULTS

The resulting projected energy demand and renewable energy production for both the ‘IP’ and ‘MRTP’ scenarios are presented graphically per sector and aggregately for both municipalities. In this manner, the maximum realisable technical potentials in terms of energy-efficiency options and renewable energy options aimed at achieving municipal energy neutrality by 2030 are provided for. These are supplemented by the projected CO_{2eq} emissions and associated cumulative additional costs per sector (and aggregately per municipality) so that the additional effect of the ‘MRTP’ scenario when compared to the ‘IP’ scenario is visualized. The municipality of De Bilt is presented first, followed by Utrecht. On the outset of the respective municipal results, a graphical overview of energy and GHG balances relating to the ‘MRTP’ scenario for 2030 is provided for.

4.1. DE BILT – THE 2030 ENERGY AND GHG BALANCE

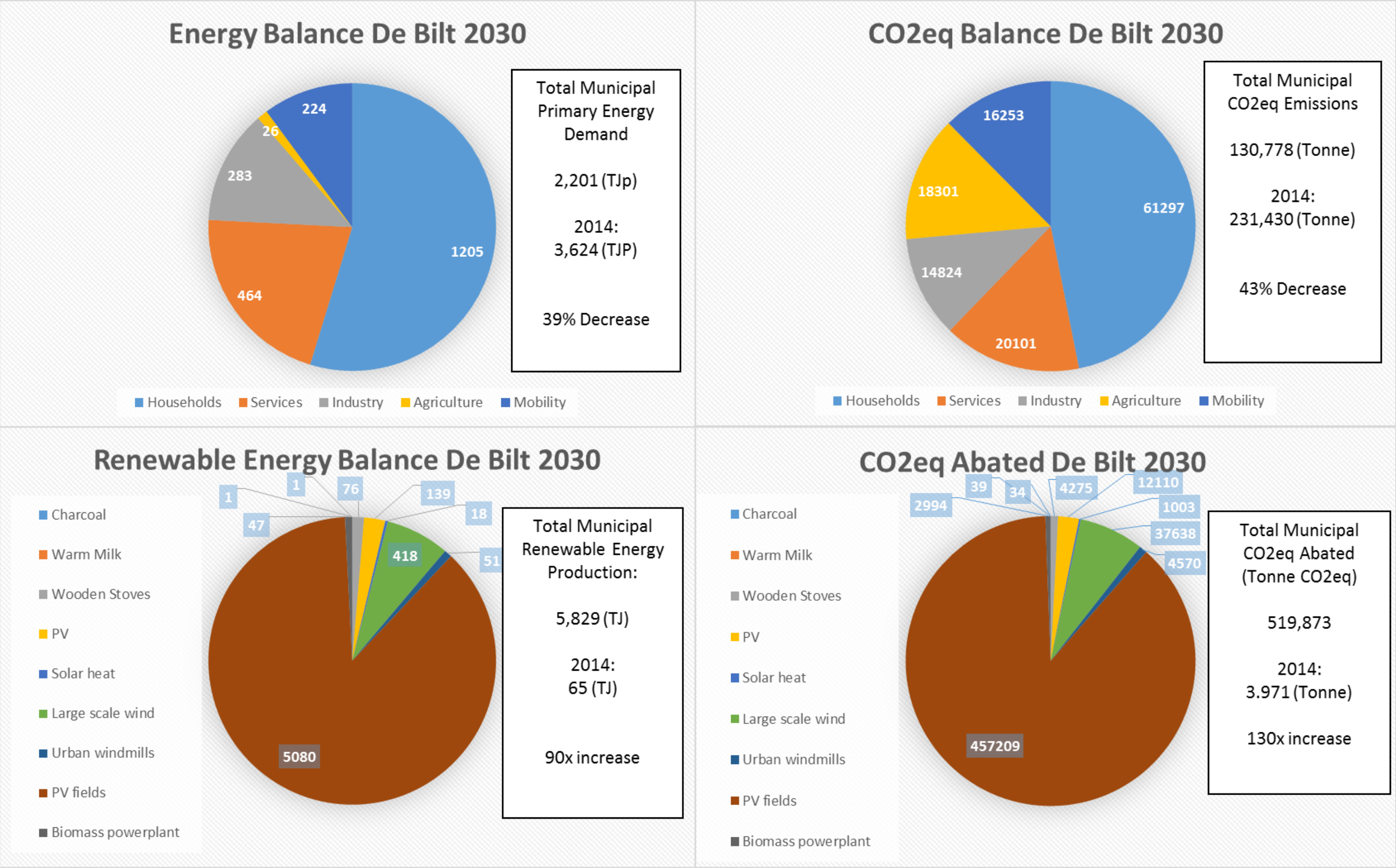
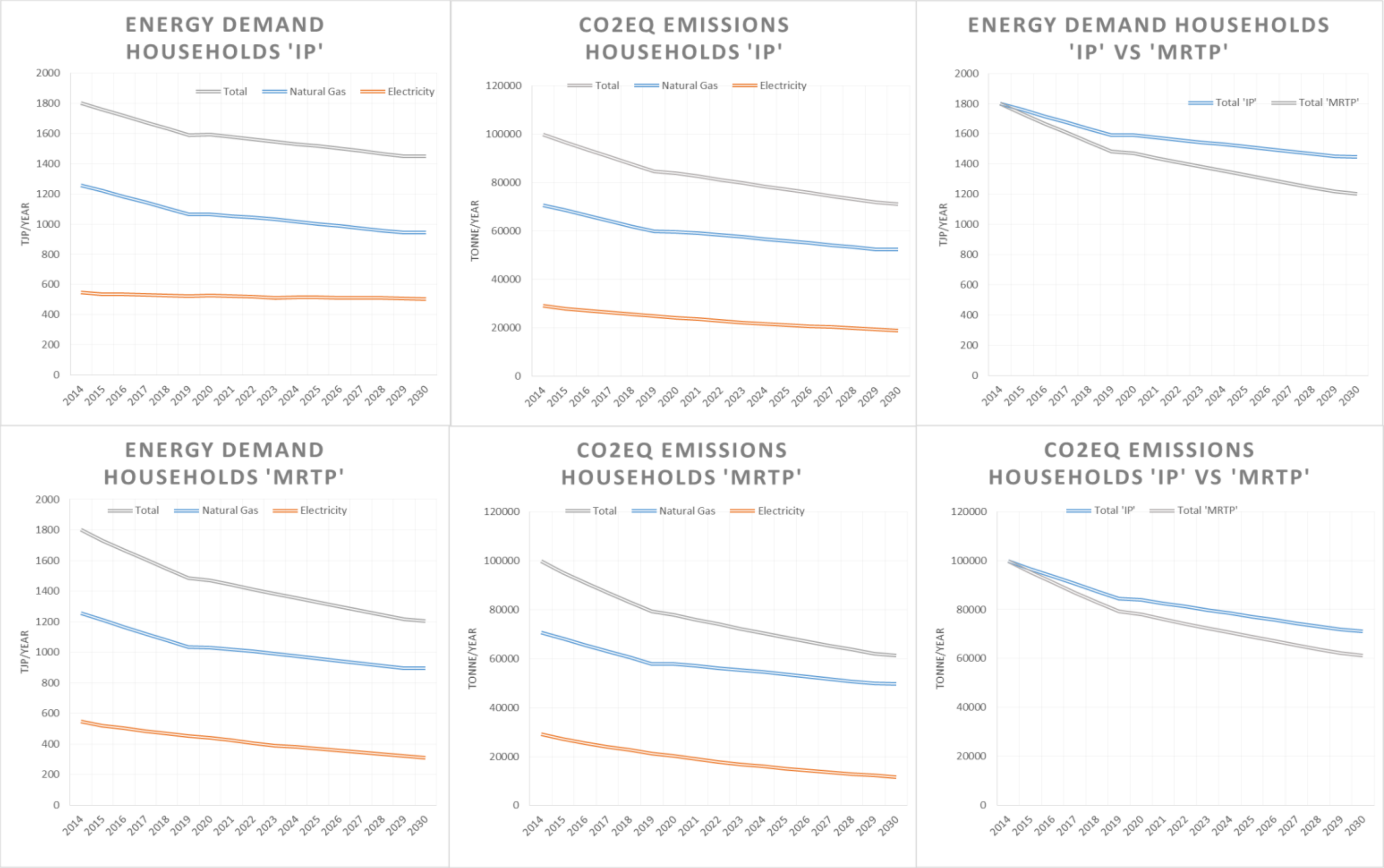


Figure 3- Projected 'MRTP' Energy, Renewable Energy, CO2eq and CO2eq Abated Balances for De Bilt in 2030

The projected energy balances for De Bilt relate to those projections derived out of the 'MRTP' scenario and are set out in more detail (per sector) in the succeeding chapters. It is apparent that De Bilt has the potential to reduce its primary energy demand by 39% compared to 2014 levels. This is closely related to an associated 43% drop in the projected 2030 CO_{2eq} balance. Regarding the potential for renewable energy production in 2030, De Bilt could potentially produce 5,829 TJ or roughly three times its own projected domestic energy requirement. This is a ninety fold increase with respect to 2014 levels. The largest contribution by far (due to the more rural characteristics of De Bilt) comes from solar PV-fields (5,080 TJ). The associated CO_{2eq} abated amounts to 519,873 tonne (approximately four times the domestic emissions), effectively a 130 fold increase over 2014 levels; also largely attributed to solar PV-fields.

When compared to the reference pathway, a total primary energy demand of 821 TJp has been avoided through the implementation of energy-efficiency measures (the total 'IP' reference primary energy demand amounts to 3,022TJp). This entails an associated 46,224 Tonne of CO_{2eq} that has been avoided (the total 'IP' reference CO_{2eq} emissions amount to 177,002 Tonne). An additional 5,673 TJ of renewable energy is produced (156 TJ is produced in the 'IP' reference scenario) and an associated 508,826 Tonne of CO_{2eq} has been abated (reference 'IP' scenario amounts to 11,047 Tonne).

De Bilt – Households


ENERGY DEMAND HOUSEHOLDS 'IP'

CO2EQ EMISSIONS HOUSEHOLDS 'IP'

ENERGY DEMAND HOUSEHOLDS 'IP' VS 'MRTP'

ENERGY DEMAND HOUSEHOLDS 'MRTP'

CO2EQ EMISSIONS HOUSEHOLDS 'MRTP'

CO2EQ EMISSIONS HOUSEHOLDS 'IP' VS 'MRTP'

Figure 4 - Energy Demand and CO2eq Emission Projections Households De Bilt

The results with respect to the energy demand for the sector households in De Bilt as projected through the ‘IP’ scenario results in a total decrease of primary energy demand of 1,807 TJp in 2014 to 1,447 TJp in 2030, effectively reducing the primary energy demand by 360TJp. The improvements are mostly ascribed to the significant drop in natural gas (3,13 TJp in total) related to the heat demand reductions when compared to the drop in electricity demand (42 TJp in total). Associated ‘IP’ CO_{2eq} emissions drop correspondingly from 29,202 Tonne to 18,825 Tonne (i.e. 10,377 Tonne in total) and the projected decreasing carbon intensities related to conventional electricity production account for the slightly larger associated decrease of emissions resulting from electricity demand.

Regarding the ‘MRTP’ scenario, the total energy demand drops from 1,807 TJp to 1,205 TJp, effectively reducing the total energy demand by 602 TJp through renovation, newly built houses and improvements in electrical efficiencies. A significant drop in electricity demand (237 TJp) is amplified by the aforementioned decreasing carbon intensities in conventional electricity production. The associated CO_{2eq} emissions drop by a corresponding 38,514 Tonne over this period. Finally, when comparing the total primary energy demand of the ‘IP’ scenario with the ‘MRTP’ scenario, yields an overall additional primary energy reduction of 242 TJp (1,447 TJp minus 1,205 TJp), and an associated additional CO_{2eq} reduction of 9,903 Tonne (71,200 minus 61,297) Tonne is projected in 2030. Effectively reducing the primary energy demand by 17% and the associated emission by 14% when compared to the ‘IP’ scenario.

De Bilt – Services

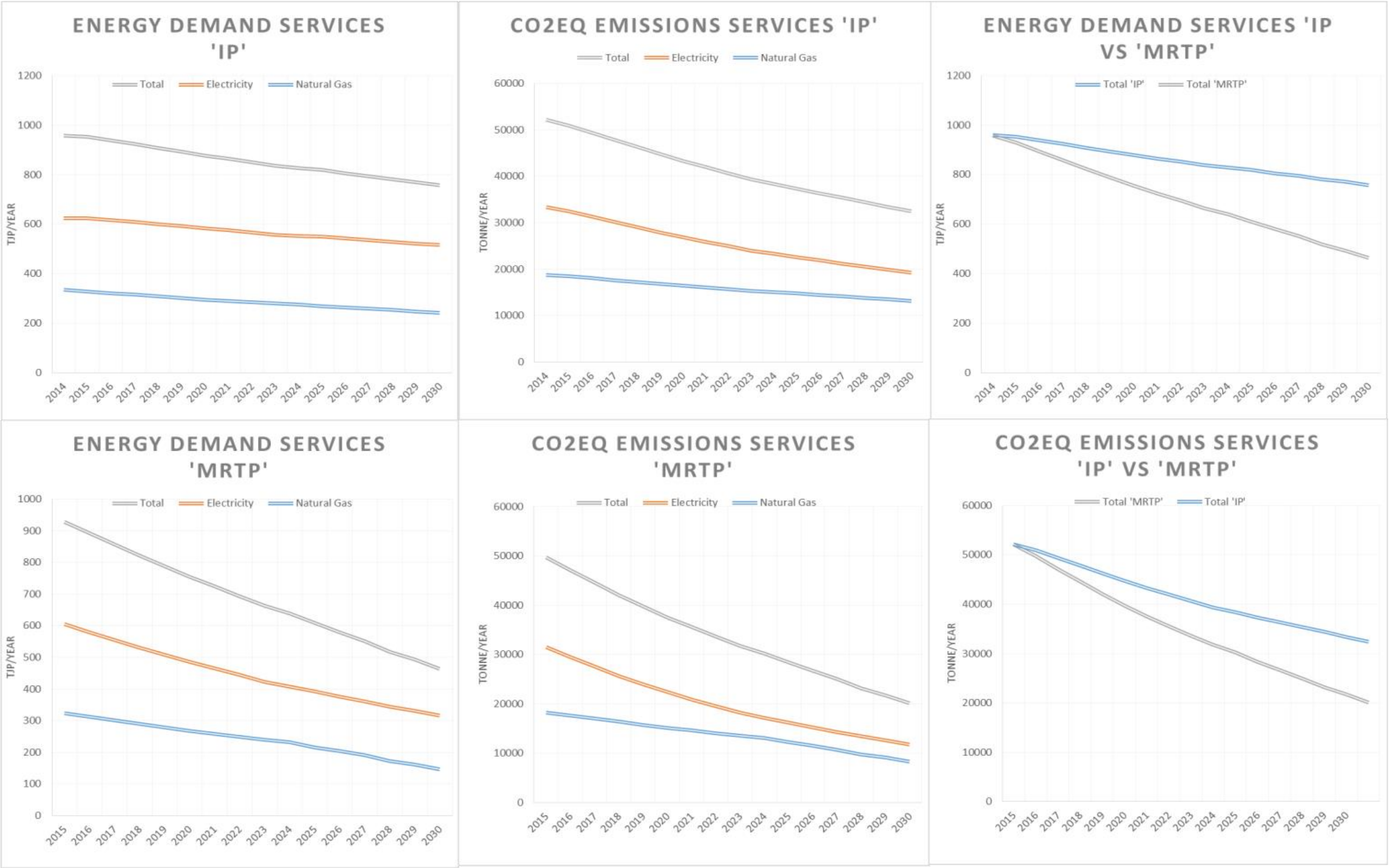


Figure 5 - Energy Demand and CO2eq Emission Projections: Services De Bilt

The results with respect to the primary energy demand of the service sector of De Bilt in 2030 for the ‘IP’ scenario indicate a total reduction from 958 TJp to 757 TJp (i.e. 201 TJp), though a reduction of 109 TJp in electricity demand and 92 TJp in natural gas demand. The associated CO_{2eq} emissions drop from 52,126 Tonne to 32427Tonne (i.e. 19,699 Tonne), which is predominantly attributed to a drop in the emissions resulting from conventional electricity production (i.e. 14,131 Tonne reduced) and associated decreasing carbon intensities.

In the ‘MRTP’ scenario, a significant energy drop of 466 TJp is observed (almost twice that of the ‘IP’ scenario), realized through significant drops in both demanded heat (i.e. 177 TJp) and electricity (i.e. 289 TJp) as a result of energy-efficiency measures relating to heat reductions through renovations and newly build services area in conjunction with continues improvements in electrical efficiencies. The associated CO_{2eq} emissions are decreased from a total of 49,747 Tonne to 20,101 Tonne (i.e. 29,646 Tonne in total). Once again, decreasing carbon intensities are reflected in the associated emissions of electricity use (dropping by 19,671 Tonne in total) whereas the associated emissions related natural gas fall by 9,969 Tonne. Comparing the scenarios yields an overall additional primary energy reduction of 294 TJp (39%) through energy-efficiency improvements and an associated additional drop of 12,326 Tonne of CO_{2eq} emissions (38%) when compared to the ‘IP’ scenario in 2030.

De Bilt – Industry

Figure 6- Energy Demand and CO2eq Emission Projections: Industry De Bilt

In the 'IP' scenario for the sector Industry, the primary energy demand is expected to rise by 37 TJp (from 348 TJp to 385 TJp), mostly attributed to an increase in the demand for natural gas (25 TJp) and a relatively small increase in the demand for electricity (7 TJp). This is reflected in the associated 'IP' CO_{2eq} emissions (experiencing a 372 Tonne increase), though slightly offset through projected decreases in carbon intensities of power generation.

The 'MRTP' scenario projections with regards to the industrial sector does not allow for allocation based on natural gas and electricity. Therefore, solely the total primary energy demand and associated CO_{2eq} emissions are provided (as stated in the methodology). Herein, a total decrease of primary energy demand is observed, reducing the demand from 348 TJp to 283 TJp (i.e. 65 TJp in total) and the associated emissions from 19,924 Tonne to 14,824 Tonne (5,100 Tonne in total).

When comparing the 'IP' with the 'MRTP' scenario, this implies a reduction of 26% (102 TJp) in primary energy demand and an associated CO_{2eq} reduction of 27% (5,472 Tonne).

De Bilt – Agriculture

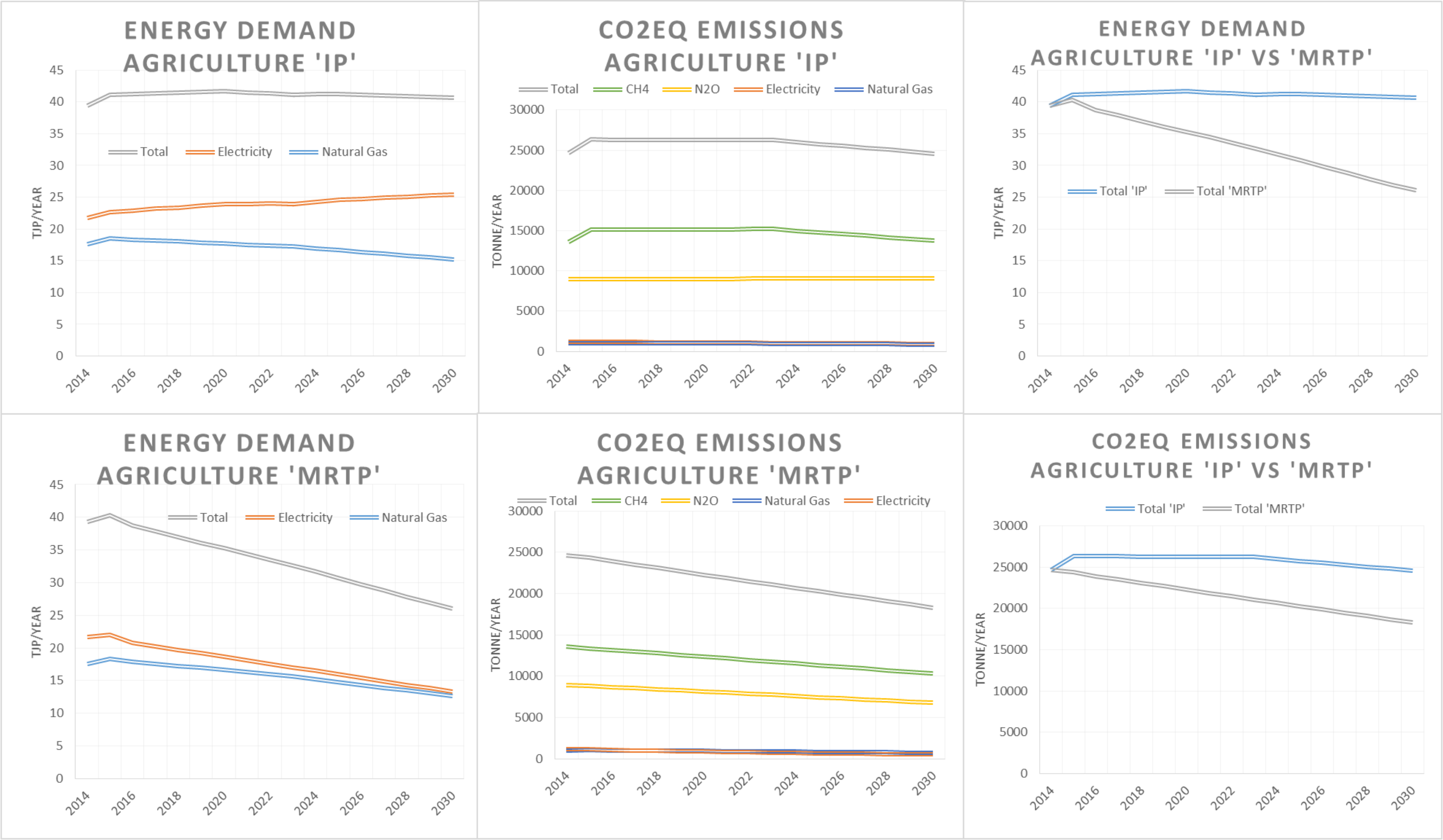


Figure 7 - Energy Demand and CO2eq Emission Projections: Agriculture De Bilt

The projected primary energy demand for the agricultural sector in the 'IP' scenario is projected to remain constant (i.e. 41 TJp) throughout the period 2015-2030 as a result of an increase in primary electricity demand (3 TJp) which is offset by a decrease in the primary energy demand of natural gas (3 TJp). The associated CO_{2eq} emissions are insignificant with those resulting from CH_4 (dropping from 26,331 Tonne to 24,576 Tonne) and N_2O (increasing from 8,950 Tonne to 9,036 Tonne) through non-energetic agricultural practices (e.g. livestock framing).

Regarding the 'MRTP' scenario, a significant primary energy reduction is achieved, decreasing from 39 TJp to 26 TJp; especially due to energy-efficiency improvements in electrical equipment resulting in a decrease of 22 TJp to 13 TJp of primary energy required for electricity. The impact hereof on the total CO_{2eq} emissions remains extremely small. Herein, reductions of 3,268 Tonne are achieved for those CO_{2eq} emissions related to CH_4 (decreasing from 13,578 Tonne to 10,310 Tonne); whereas those related to N_2O drop by 2,173 Tonne (decreasing from 8,950 Tonne to 6,777 Tonne).

The total primary energy reduction of the 'MRTP' scenario when compared to the 'IP' scenario amounts to 15 TJp (i.e. 37%) and the associated CO_{2eq} emissions are reduced by 6,275 Tonne (or 25%).

De Bilt – Mobility

Figure 8 - Energy Demand and CO2eq Emission Projections: Mobility De Bilt

The primary energy demand of the sector mobility in the ‘IP’ scenario decreases from 473 TJp to 392 TJp. This is constituted by a decrease in oil-products from 425 TJp to 314 TJp. Biofuels increase their primary energy usage from 45 TJp to 73 TJp whereas the primary energy supply of electricity related to hybrids and electric vehicles increases from 3 TJp to 6 TJp. The associated CO_{2eq} emission drop correspondingly from 36,739 Tonne to 28,504 Tonne. Herein, the increase in the primary energy demand for electricity is offset by the decreasing carbon efficiencies of power generation, resulting in an overall drop of emissions resulting from electricity usage (dropping from 16,864 Tonne to 13,084 Tonne).

In the ‘MRTP’ scenario the total primary energy demand drops from 473 TJp to 224 TJp due to numerous efficiency improvements and increased penetration of hybrid and electric vehicles. Power train and weight reductions result in the largest decrease of 52 TJp, closely followed by electric cars, further decreasing the demand by 50 TJp (this trend is expect to continue, making electric cars a very promising prospect with regard to primary energy reduction). Biofuels level off at a reduction of about 25 TJp while the implementation of hybrids accounts for a steadily increasing primary energy demand reduction of 18 TJp in total. The options relating to improved aerodynamics, LRRT, TPMS and eco-driving amount to a total reduction of less than 10 TJp.

The associated CO_{2eq} emissions in the 'MRTP' scenario drop significantly from 36,739 Tonne to 16,253 Tonne (i.e. by 20,486 Tonne). Especially the powertrain and weight reduction measures abate a significant part of 3,827 Tonne by 2030. Biofuels and hybrids negate 1,840 Tonne and 1,320 Tonne respectively, closely followed by Eco-driving (750 Tonne) and TPMS (438 Tonne). Improved aerodynamics abate approximately 428 Tonne, whereas electric cars abate roughly 44 Tonne.

When compared to the 'IP' scenario, the 'MRTP' scenario reduces total primary energy demand in 2030 from 392 TJp to 224 TJp (i.e. a 168 TJp reduction, or a 43% reduction), whereas the associated CO_{2eq} reduction amounts to 12,251 Tonne (from 28,594 Tonne to 16,253 Tonne; also a 43% reduction).

De Bilt – Renewable Energy Production

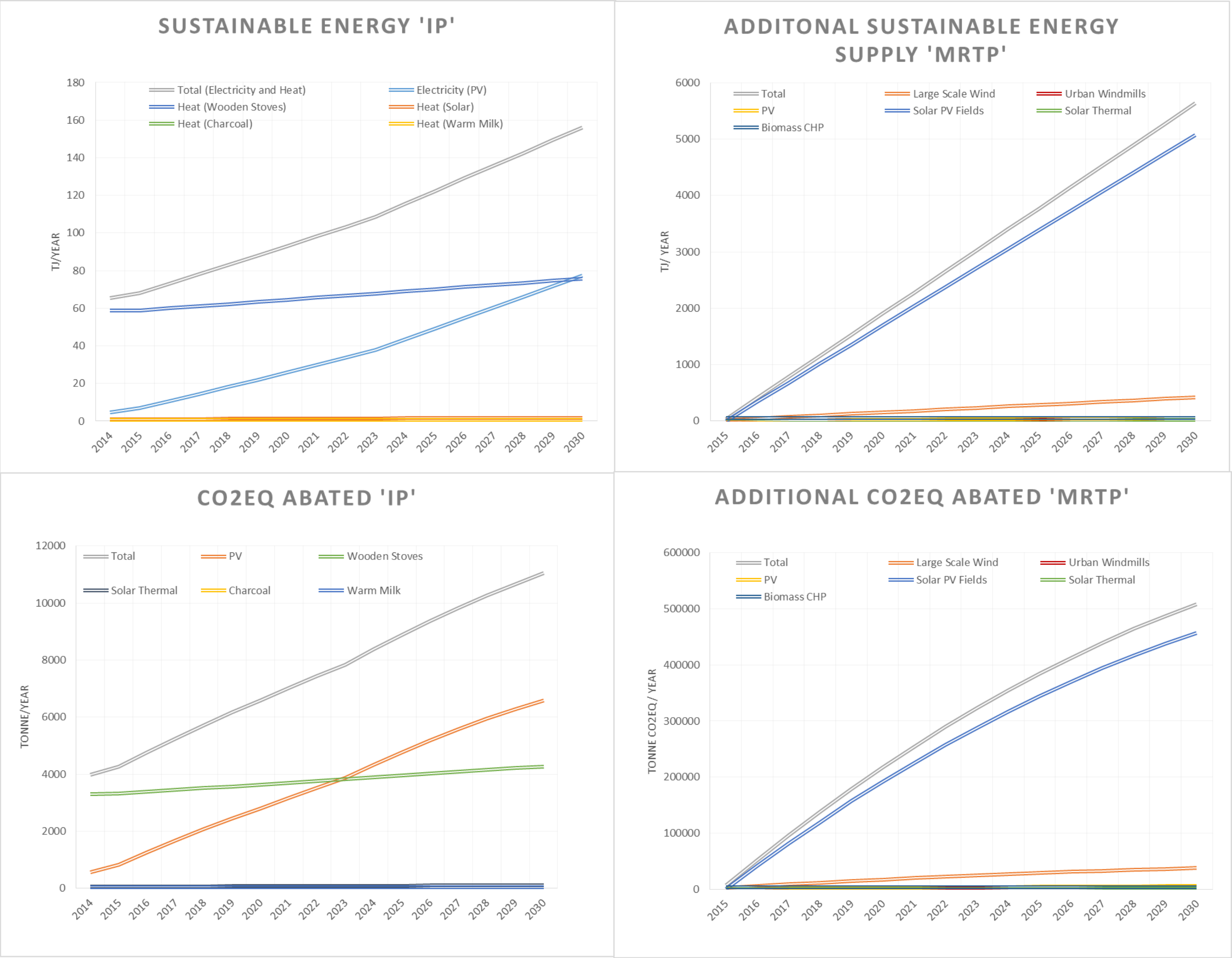


Figure 9 - Sustainable Energy Supply and Associated CO2eq Abatement Potentials: De Bilt

The sustainable energy supply in the 'IP' scenario increases from 65 TJ to 156 TJ (i.e. 91 TJ) which is predominantly attributed to a rise in additional PV-panels (increasing from 4.5 TJ to 77.3 TJ) and a slight increase in heat supplied via wooden stoves (58.7 TJ to 75.8 TJ). The other options supply a fairly insignificant amount and are not expected to rise meaningfully within this scenario.

The associated abated CO_{2eq} increases more drastically from 3,971 Tonne to 11,047 Tonne (effectively abating an additional 7,076 Tonne). This is predominantly caused by the PV-panels as being the sole renewable energy technology that produces electricity in this scenario that is assumed to otherwise be produced in conventional power plants. The abatement through wooden stoves increases from 3,294 Tonne to 4,275 Tonne and the other options remain (fairly) constant at relatively insignificant amounts.

With regards to the production of sustainable energy in the ‘MRTP’ scenario, De Bilt has the potential to produce a total of 5,638 TJ of energy in 2030 of which 5,080 TJ is generated in solar PV fields. This options outstrips the other sustainable energy production options (cumulatively producing 558 TJ) by a large amount. Large scale wind can produce 418 TJ in 2030, followed by an additional 53 TJ that can be generated through PV-panels (amounting to 125,8 TJ in total produced by PV-panels). 51 TJ is supplied through urban windmills and 47 TJ through the biomass plant. Finally, an additional 16 TJ is produced through solar thermal systems.

The associated additional CO_{2eq} that is abated in this ‘MRTP’ scenario amounts to 506,882 Tonne in total, of which 457,208 Tonne is abated through the Solar PV fields. The large scale wind turbines can abate an additional 37,638 Tonne, whereas PV-panels can abated 5,513 Tonne. Urban windmills, in turn, potentially abate 4,570 Tonne, while the Biomass plant abates 1,049 Tonne and the Solar thermal systems abate 901 Tonne.

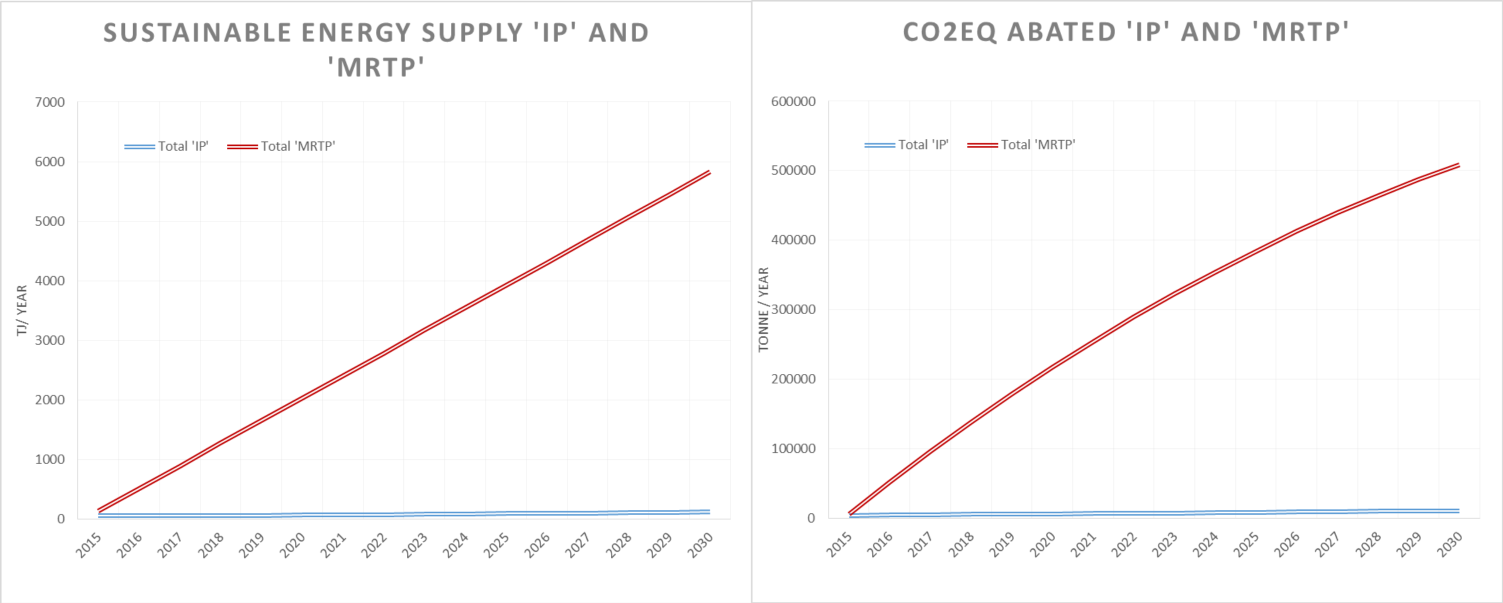


Figure 10 - Comparison of 'IP' and 'MRTP' Projections in Sustainable Energy Supply and Associated CO2e Emissions: De Bilt

When comparing the ‘IP’ Scenario with the ‘MRTP’ Scenario, the 5,829 TJ that is projected in the ‘MRTP’ scenario amount to an increased energy production that is a factor 48 times larger than the 122 TJ that is produced in the ‘IP’ scenario. This is further reflected in the associated total abated CO_{2eq} emissions which amount to 519,873 Tonne in the ‘MRTP’ scenario and 11,047 Tonne in the ‘IP’ scenario (i.e. 47 times as much CO_{2eq} is abated in the ‘MRTP’ scenario when compared to the ‘IP’ scenario).

De Bilt – Associated Costs and Comparisons

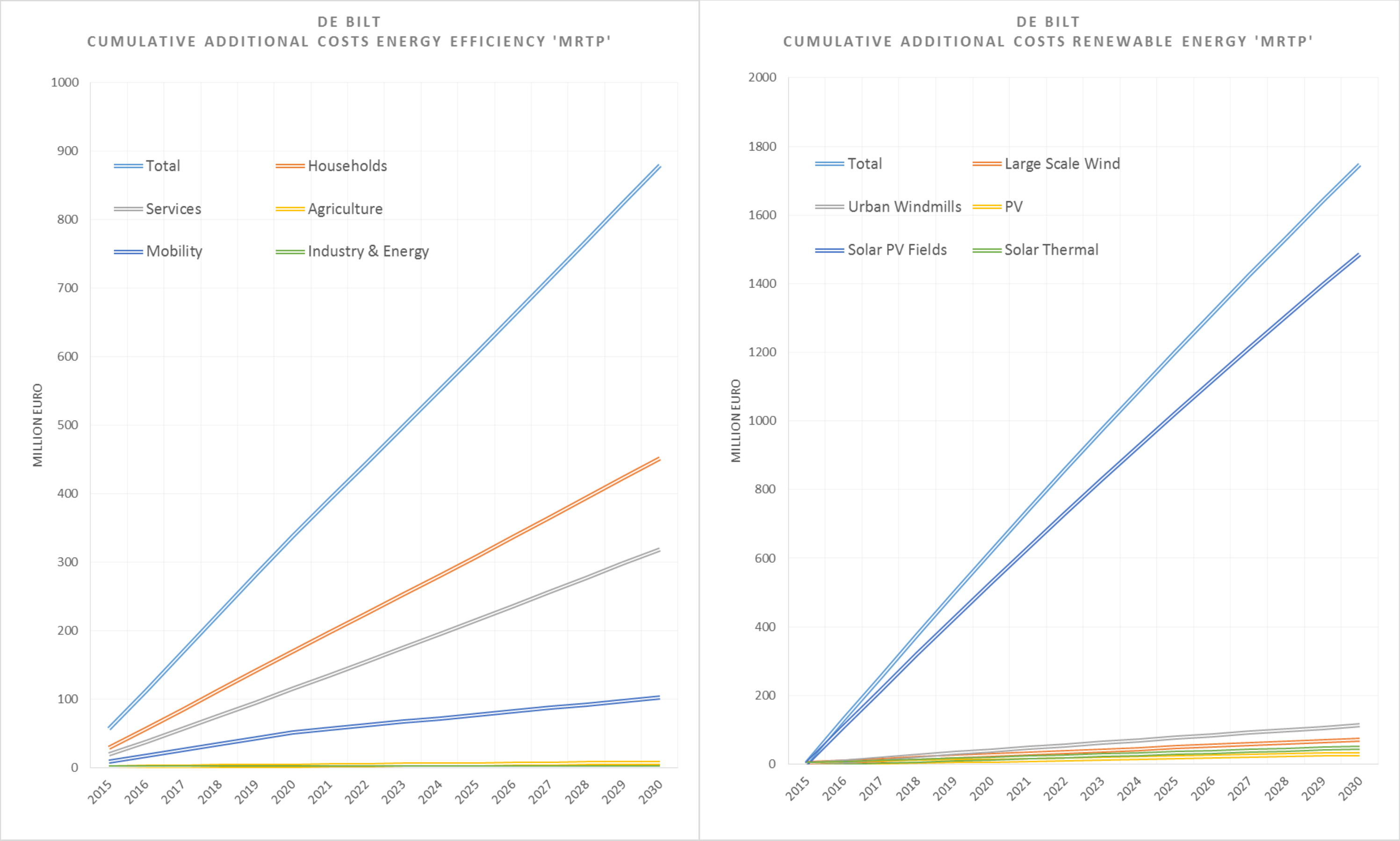


Figure 11 - Projected Cumulative Additional Costs for the 'MRTP' Projections related to Energy Efficiency & Renewable Energy Options for De Bilt

The total cumulative additional costs related to the projected energy-efficiency options for De Bilt in 2030 amount to 879 million euros. 451 million (or 51% of the total costs) hereof is associated with these efficiency improvements in the sector households (i.e. renovating and the construction of new, more energy-efficient, housing). Analysed options relating to the service sector are expected to cost 319 million (or 36%), followed by the mobility sector amounting to cumulative costs of 102 million euros (approx. 12%). Finally, the costs related to the agricultural sector amount to 7 million (approx. 0.8%) whilst those related to the industry and energy sector are framed at zero euros (see chapter 3.7.1).

The total cumulative costs associated with the projected renewable energy options for De Bilt in 2030 amount to 1,747 Million euros. A very significant part of this (i.e. 1,486 million or 85%) is attributed to the costs associated with the development of PV fields. The combined costs of the remaining options equates to 261 million (i.e. 15%), the largest part of which is ascribed to the development of urban windmills (i.e. 113 million), followed by large scale wind turbines (71 million or 4%) and solar thermal systems (48 million or approx. 3%). The lowest costs are associated with the instalment of PV systems, which amount to 29 million euros or approx. 2% of total cumulative costs in domestic renewable energy production development.

The projected energy-efficiency and renewable energy production options in the ‘MRTP’ scenario are ordered and presented in Table XLIX with respect to the energy-efficiency options and Table L regarding the renewable energy options. The data is reflective of the additional energy saved, CO_{2eq} abated and associated costs in the ‘MRTP’ scenario as compared to the ‘IP’ reference scenario. This data is ordered and numbered in order to reflect the order of contribution of the different energy-efficiency and renewable energy options.

Organised Contribution of Projected Energy-efficiency Options, Associated CO2eq Abated and Associated Cumulative Costs in 2030					
Energy-efficiency Option		Associated CO_{2eq} Abated		Associated Costs	
Sector	Energy Saved (TJp)	Sector	CO_{2eq} Abated (Tonne)	Sector	Cumulative Costs (Million Euro)
1. Services	294	1. Services	12,325	1. Households	451
2. Households	242	2. Mobility	12,251	2. Services	319
3. Mobility	169	3. Households	9,902	3. Mobility	102
4. Industry	102	4. Agriculture	6,275	4. Agriculture	7
5. Agriculture	15	5. Industry	5,471	5. Industry	0
Total	821	Total	46,225	Total	879

Table XLIX - Organised Contribution of Projected Energy-efficiency Options and Associated CO2eq Abated and Cumulative Costs for De Bilt in 2030

When ordered according to the primary energy saved, the service sector is expected to save 294 TJp (or approx. 36%) in the ‘MRTP’ scenario when compared to the ‘IP’ scenario. A fairly equivalent contribution of 242 TJp (approx. 29%) saved is made through energy-efficiency improvements in the sector households. The mobility sector saves about half the amount of energy of the service sector at 169 TJp (or 21%) saved, followed by 102 TJp (approx. 12%) saved through improvements in the industry and energy sector. The potential energy saved in the agricultural sector is fairly insignificant, amounting to 15 TJp (or 2%) saved.

Distributed by associated CO_{2eq} abated, the service sector can potentially abated the largest amount (i.e. 12,325 Tonne or 27%), closely followed by the mobility sector (12,251 Tonne or also 27%) and the sector households (9,902 Tonne or 21%). The relatively low position of the sector households when compared to the aforementioned potential primary energy saved is explained through a relatively small drop in electricity demand (which is converted to the required associated primary energy demanded) when compared to the service sector and a shift away from conventional fuels in the mobility sector. These have a limited effect on the total primary energy saved but a large effect on the associated abated CO_{2eq} through lowered emission factors and sustainable fuels. The relatively large amount of CO_{2eq} abated through developments in the agricultural sector (i.e. 6,275 Tonne or 14%) when compared to the small amount of energy saved, is attributed to developments reducing the emitted CH_4 and N_2O which are released as a consequence of agricultural practices that are not (directly) related to energy usage. Finally, abatements in the industry and energy sector amount to 5,471 Tonne (or approx. 12%), which is proportional to the potential amount of energy sector saved through energy-efficiency options.

When contrasted with the associated costs, energy-efficiency improvements in the sector households are relatively expensive at 451 million euro or 51% (i.e. highest costs but second in primary energy saved and third in terms of abatement potential). The service sector is the second most costly option at 319 million (approx. 36%) but does deliver the highest potentials in terms of energy savings and CO_{2eq} abatement; rendering it a more viable sector than the sector households. The costs associated with the mobility sector are fairly low (i.e. 102 million or 12% of total costs) whereas especially the related abated CO_{2eq} is of the same magnitude as the service sector. Effectively, energy-efficiency improvements in the mobility sector can greatly reduce CO_{2eq} emissions against relatively low costs. To a lesser extend this holds for the agricultural sector as well; abating a respective amount of CO_{2eq} (i.e. approximately 14% of the total) against a fraction of the potential total costs (i.e. 7 million or 0.8%), making it very cost-efficient yet with a limited absolute impact when compared to the aforementioned sectors. Finally, the industrial sector improvements are assumed to not entail any costs (see chapter 3.7.1.) rendering them highly cost-efficient. However, the associated energy saving and abatement potentials of these options are relatively low as well, effectively limiting the impact to the lowest absolute abatement potential and second to lowest energy saving potential.

Organised Contribution of Projected Renewable Energy Production Options and Associated CO2eq Abated and Cumulative Costs in 2030

Renewable Energy Option		Associated CO_{2eq} Abated		Associated Costs	
RES Option	Energy Produced (TJ)	RES Option	CO_{2eq} Abated (Tonne)	Sector	Cumulative Costs (Million Euro)
1. PV fields	5,080	1. PV fields	457,209	1. PV fields	1,486
2. Large scale wind	418	2. Large scale wind	37,638	2. Urban windmills	113
3. PV panels	61	3. PV panels	5,513	3. Large scale wind	71
4. Urban windmills	51	4. Urban windmills	4,570	4. Solar thermal	48
5. Biomass CHP plant	47	5. Biomass CHP plant	2,994	5. PV panels	29
6. Solar thermal	16	6. Solar thermal	901	6. Biomass CHP plant	0
7. RWZI (biogas)	0	7. RWZI (biogas)	0	7. RWZI (biogas)	0
8. Charcoal burning	0	8. Charcoal burning	0	8. Charcoal burning	0
9. Warm milk	0	9. Warm milk	0	9. Warm milk	0
10. Wooden stoves	0	10. Wooden stoves	0	10. Wooden stoves	0
Total	5,673	Total	508,826	Total	1,747

Table L - Organised Contribution of Projected Renewable Energy Production Options and Associated CO2eq Abated and Cumulative costs for De Bilt in 2030

In terms of renewable energy produced, PV fields contribute the most by far (5,080 TJ, almost 90% of the total). This large discrepancy is reflected in the associated CO_{2eq} abated (457,209 Tonne or approx. 90%) and the associated costs (1,486 Million or approx. 85%). Large scale wind turbines are the second biggest contributor in terms of both renewable energy produced (approx. 7% of the total at 418 TJ) and associated CO_{2eq} abated (approx. 7% at 37,638 Tonne) but against relatively lowered costs (approx. 4% or 71 million), making it a more viable option when compared to urban windmills that have relatively high costs (i.e. 113 million or approx. 6%) against fairly low contributions in renewable energy produced (approx. 0.9% at 51 TJ) and associated CO_{2eq} abated (approx. 0.9% at 4,570 Tonne). PV panels, deliver about 1% (i.e. 61 TJ) of total sustainable energy produced and CO_{2eq} abated (5,513 Tonne or 0.9%) but against almost 1.7% of the costs (i.e. 29 million), rendering it a less financially viable option than the PV fields and large scale wind but more so than the urban windmills. The solar thermal systems contribute about 0.3% in terms of renewable energy supply (i.e. 16 TJ) and about 0.2% in terms of abated CO_{2eq} (901 Tonne) whilst accounting for approx. 3% (48 million) of the total costs; rendering it one of the least viable renewable energy options in terms of renewable energy production, CO_{2eq} abatement and associated costs. The costs of the biomass CHP plant are unknown but its contribution in terms of energy supply and abatement potential is fairly limited when compared to the other identified options (excluding solar thermal systems). Accounting for about 0.8% (or 47 TJ) of renewable energy produced and 0.6% (or 2,994 Tonne) of the abatement potential for De Bilt in 2030 according to the 'MRTP' scenario as compared to the 'IP' scenario.

Additional cumulative costs relating to the RWZI (biogas derived out of sewage), charcoal burning, heat from warm milk and wooden stoves are framed at zero since herein there is no assumed difference between the 'IP' (i.e. reference) and 'MRTP' scenario.

4.2. Utrecht The 2030 Energy and GHG Balance

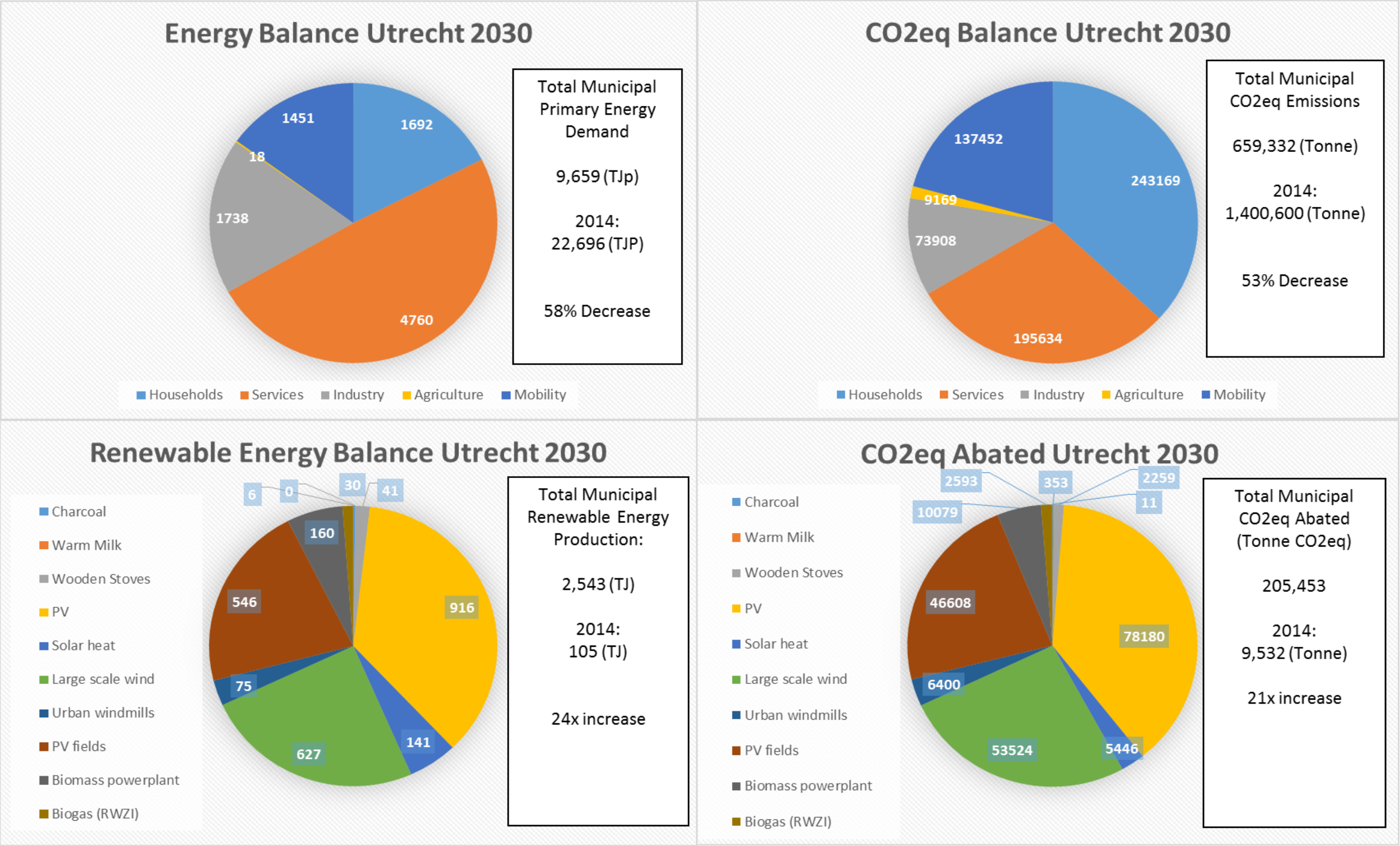


Figure 12 - Projected 'MRTP' Energy, Renewable Energy, CO2eq and CO2eq Abated Balances for Utrecht in 2030

The projected energy balances for Utrecht relate to those projections derived out of the 'MRTP' scenario and are set out in more detail (per sector) in the succeeding chapters. It is apparent that the municipality of Utrecht has the potential to reduce its primary energy demand by 58% compared to 2014 levels through energy efficiency improvements. This is closely related to an associated 53% drop in the projected 2030 CO_{2eq} balance. Regarding the potential for renewable energy production in 2030, Utrecht could potentially produce 2,512 TJ or roughly a quarter of its own projected domestic energy requirement. This is a twenty-four fold increase with respect to 2014 levels. The largest comes from PV-systems (916 TJ). The total associated CO_{2eq} abated amounts to 202,860 tonne (approximately one third of the domestic emissions), effectively a constituting a 21 fold increase over 2014 levels.

Furthermore, when compared to the reference pathway, a total primary energy demand of 9,330 TJp has been avoided due to the implemented energy-efficiency measures (the total reference primary energy demand amounts to 18,989 TJp) and an associated 313,759 Tonne of CO_{2eq} emissions have been avoided (total reference CO_{2eq} emissions amount to 973,091 Tonne). An additional 1,911 TJ of renewable energy is produced (601 TJ in the reference scenario) and an additional 154,243 Tonne of CO_{2eq} has been abated (reference scenario amounts to 48,617 Tonne).

Utrecht – Households

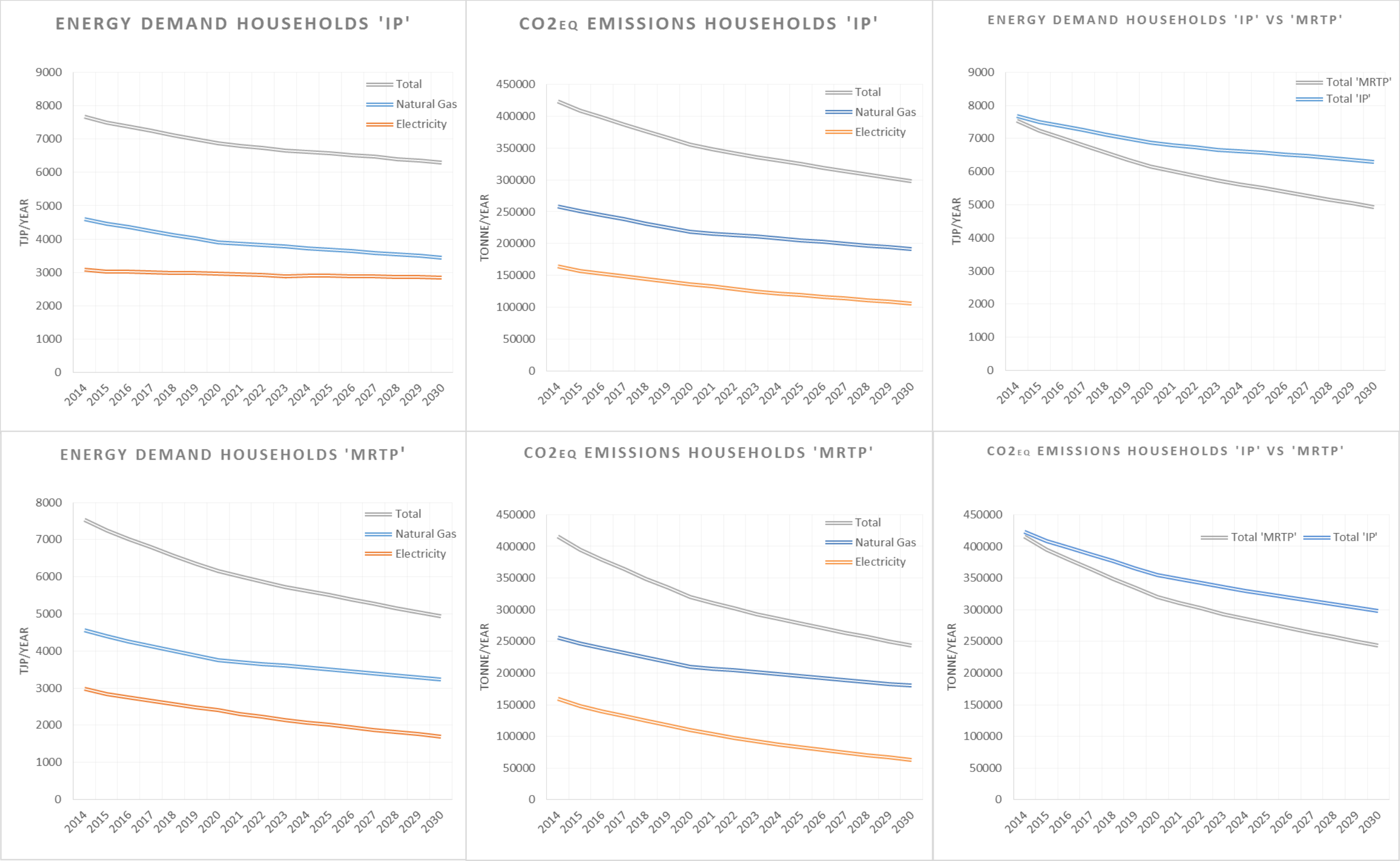


Figure 13 - Energy Demand and CO2eq Emission Projections: Households Utrecht

The results with respect to the energy demand for the sector households in Utrecht as projected through the 'IP' scenario results in a total decrease of primary energy demand of 7,674 TJp in 2014 to 6,292 TJp in 2030, effectively reducing the primary energy demand by 1,382 TJp. The improvements are mostly ascribed to the drop in natural gas demand (1,145 TJp in total, related to the heat demand reductions) when compared to the drop in electricity demand (237 TJp in total). Associated 'IP' CO_{2eq} emissions drop correspondingly from 422,912 Tonne to 297,737 Tonne (i.e. 125,175 Tonne in total) and the projected decreasing carbon intensities related to conventional electricity production account for the slightly larger associated decrease of emissions resulting from electricity demand.

Regarding the 'MRTP' scenario, the total energy demand drops from 7,674 TJp to 4,931 TJp, effectively reducing the total energy demand by 2,743 TJp through renovation, newly built houses and improvements in electrical efficiencies. A significant drop in electricity demand (1,297 TJp) is amplified by the aforementioned decreasing carbon intensities in conventional electricity production. The associated CO_{2eq} emissions drop by a corresponding 172,525 Tonne over this period. Finally, when comparing the total primary energy demand of 2030 for the 'IP' scenario with the 'MRTP' scenario, this yields an overall additional primary energy reduction of 1,361 TJp (6,292 TJp minus 4,931 TJp), and an associated additional CO_{2eq} reduction of 54,568 Tonne (297,737 minus 243,169) is projected, effectively reducing the primary energy demand by 22% and the associated emission by 18% when compared to the 'IP' scenario.

Utrecht – Services

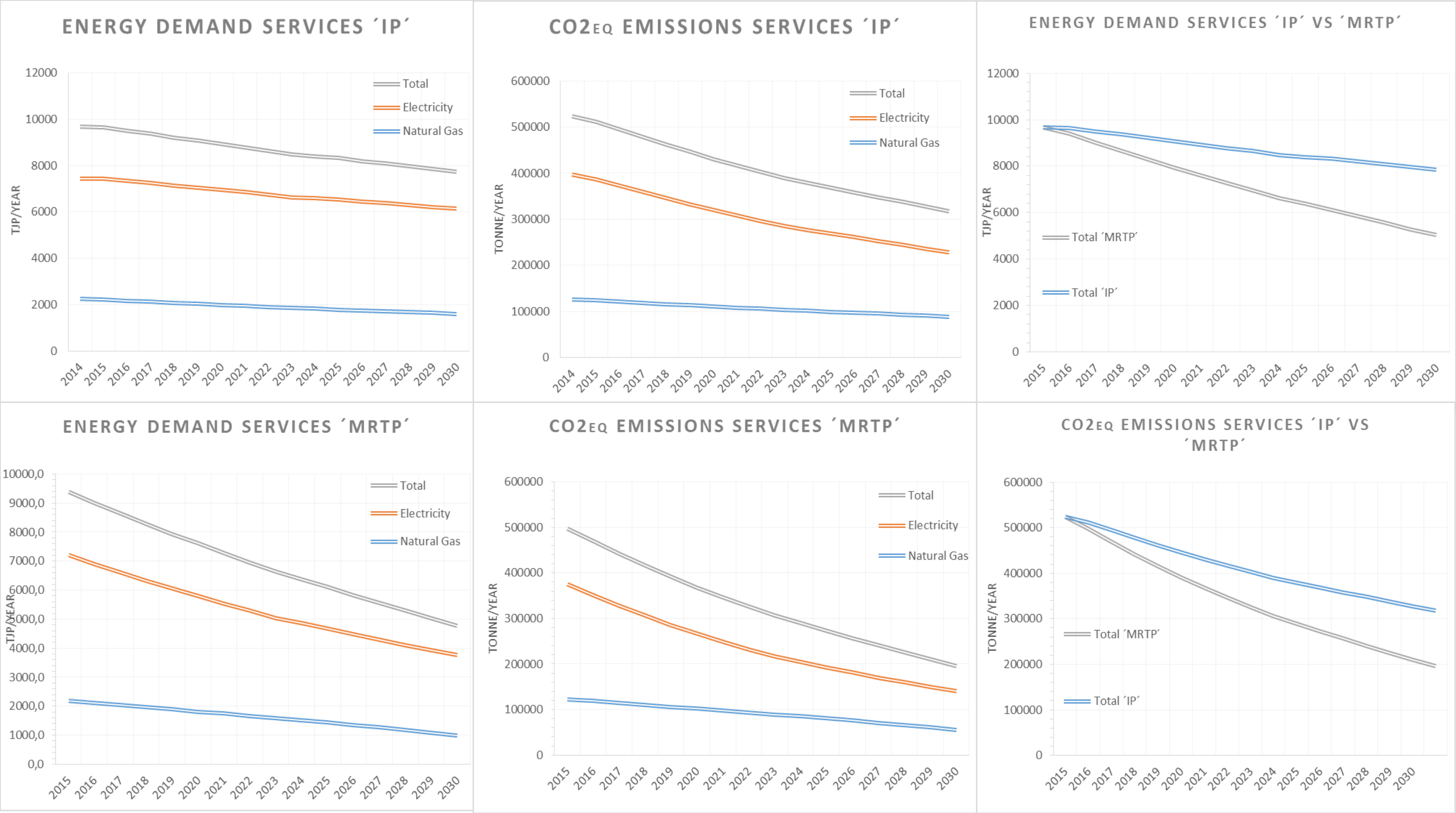


Figure 14 - Energy Demand and CO2eq Emission Projections: Services Utrecht

The results with respect to the primary energy demand of the service sector of De Bilt in 2030 for the 'IP' scenario indicate a total reduction from 9,685 TJp to 7,736 TJp (i.e. 1,949 TJp), though a reduction of 1,301 TJp in electricity demand and 648 TJp in natural gas demand. The associated CO_{2eq} emissions drop from 523,540 Tonne to 317,772 Tonne (i.e. 205,768 Tonne), which is predominantly attributed to a drop in the emissions resulting from conventional electricity production (i.e. 168,239 Tonne reduced) and associated decreasing carbon intensities.

In the 'MRTP' scenario, a significant energy drop of 4,628 TJp is observed (almost twice that of the 'IP' scenario), realized through significant drops in both demanded heat (i.e. 1,192 TJp) and electricity (i.e. 3,436 TJp) as a result of energy-efficiency measures relating to heat reductions through renovations and newly build services area in conjunction with continues improvements in electrical efficiencies. The associated CO_{2eq} emissions are decreased from a total of 497,505 Tonne to 195,634 Tonne (i.e. 301,871 Tonne in total). Once again, decreasing carbon intensities are reflected in the associated emissions of electricity use (dropping by 234,195 Tonne in total) whereas the associated emissions related natural gas fall by 57,676 Tonne. Comparing the scenarios yields an overall additional primary energy reduction of 2,830 TJp (36%) through energy-efficiency improvements and an associated additional drop of 122,139 Tonne of CO_{2eq} emissions (38%) when compared to the 'IP' scenario in 2030.

Utrecht – Industry

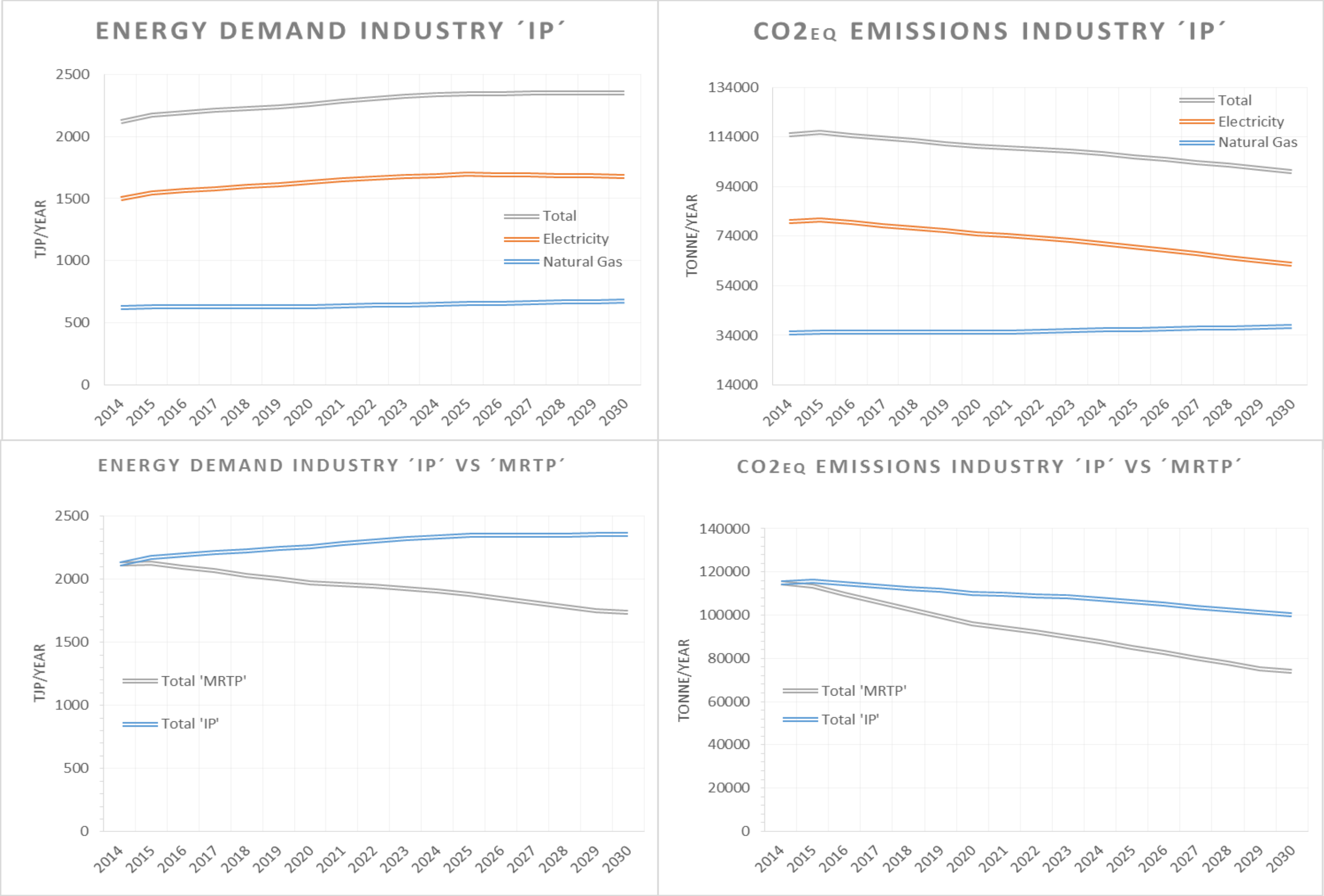


Figure 15 - Energy Demand and CO2eq Emission Projections: Industry Utrecht

In the ‘IP’ scenario for the sector Industry, the primary energy demand is expected to rise by 235 TJp (from 2,120 TJp to 2,355 TJp), mostly attributed to an increase in the demand for natural gas (181 TJp) and a relatively small increase in the demand for electricity (53 TJp). This is reflected in the associated ‘IP’ CO_{2eq} emissions (experiencing a 14,809 Tonne increase), wherein the CO_{2eq} emissions are slightly offset through projected decreases in carbon intensities of power generation.

The ‘MRTP’ scenario projections with regards to the industrial sector does not allow for allocation based on natural gas and electricity. Therefore, solely the total primary energy demand and associated CO_{2eq} emissions are provided (as stated in the methodology). Herein, a total decrease of primary energy demand is observed, reducing the demand from 2,120 TJp to 1,738 TJp (i.e. 382 TJp in total) and the associated emissions from 114,955 Tonne to 73,907 Tonne (41,048 Tonne in total).

When comparing the ‘IP’ with the ‘MRTP’ scenario, this implies a reduction of 26% (617 TJp) in primary energy demand and an associated CO_{2eq} reduction of 26% (26,239 Tonne).

Utrecht – Agriculture

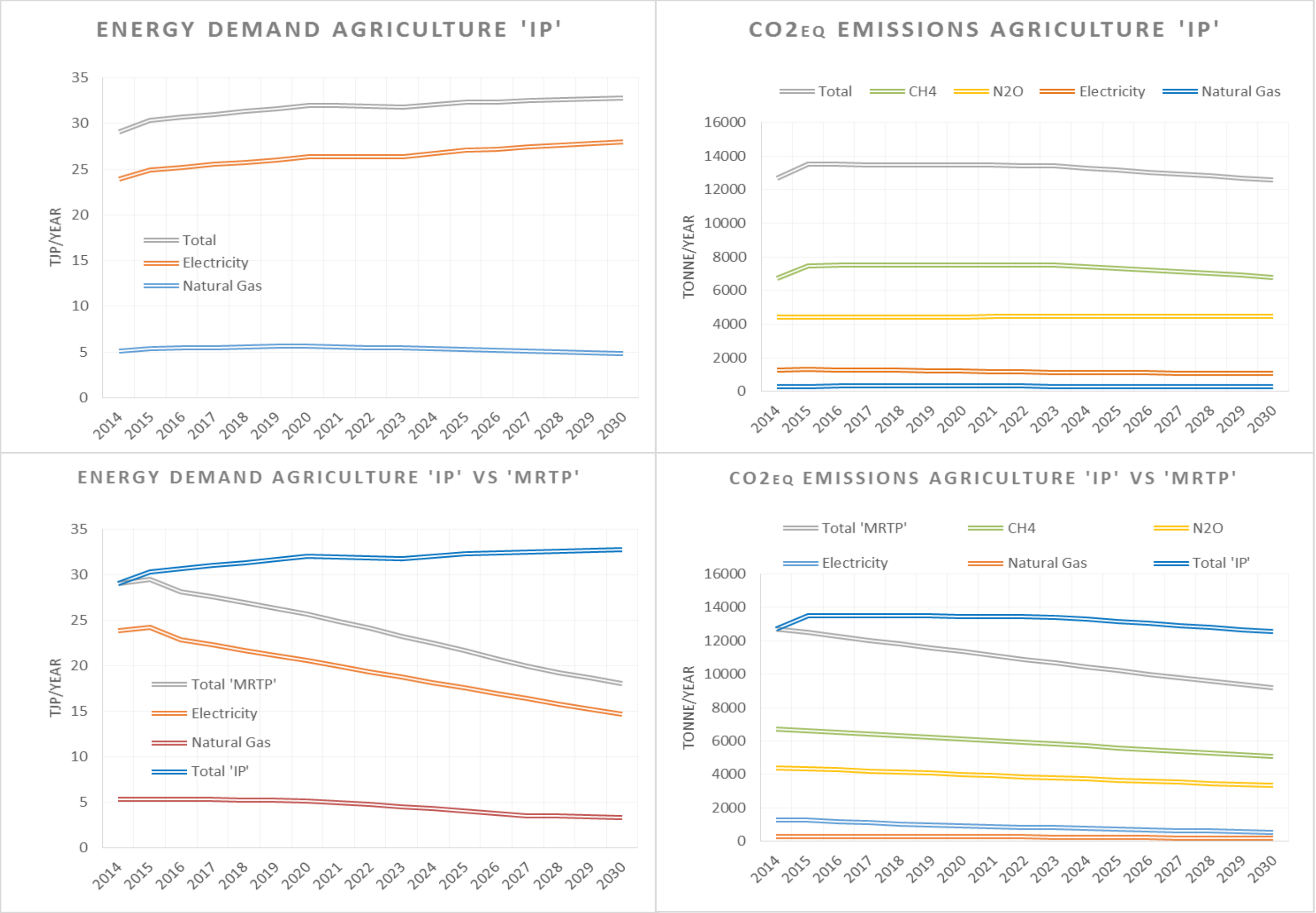


Figure 16 - Energy Demand and CO2eq Emission Projections: Agriculture Utrecht

The projected primary energy demand for the agricultural sector in the ‘IP’ scenario is projected to rise slightly from 29.1 TJp to 32.8 TJp throughout the period 2015-2030 as a result of an increase in primary electricity demand (5 TJp) and a constant demand for natural gas (5 TJp). The associated CO_{2eq} emissions are fairly insignificant with those resulting from CH_4 (rising from 6,715 Tonne to 6,799 Tonne) and N_2O (increasing from 4,405 Tonne to 4,447 Tonne) through non-energetic agricultural practices (e.g. livestock framing).

Regarding the ‘MRTP’ scenario, a significant primary energy reduction is achieved, decreasing from 29.1 TJp to 18 TJp; especially due to energy-efficiency improvements in electrical equipment resulting in a decrease of 23.9 TJp to 14.7 TJp of primary energy required as electricity. The impact hereof on the total CO_{2eq} emissions remains fairly small. Herein, total reductions of 3,518 Tonne are achieved of which those CO_{2eq} emissions related to CH_4 amount to 1,615 Tonne (decreasing from 6,714 Tonne to 5,099 Tonne); whereas those related to N_2O drop by 1,070 Tonne (decreasing from 4,405 Tonne to 3,355 Tonne).

The total primary energy reduction of the ‘MRTP’ scenario when compared to the ‘IP’ scenario amounts to 14.8TJp (i.e. 45%) and the associated CO_{2eq} emissions are reduced by 3,387 Tonne (or 27%).

Utrecht – Mobility

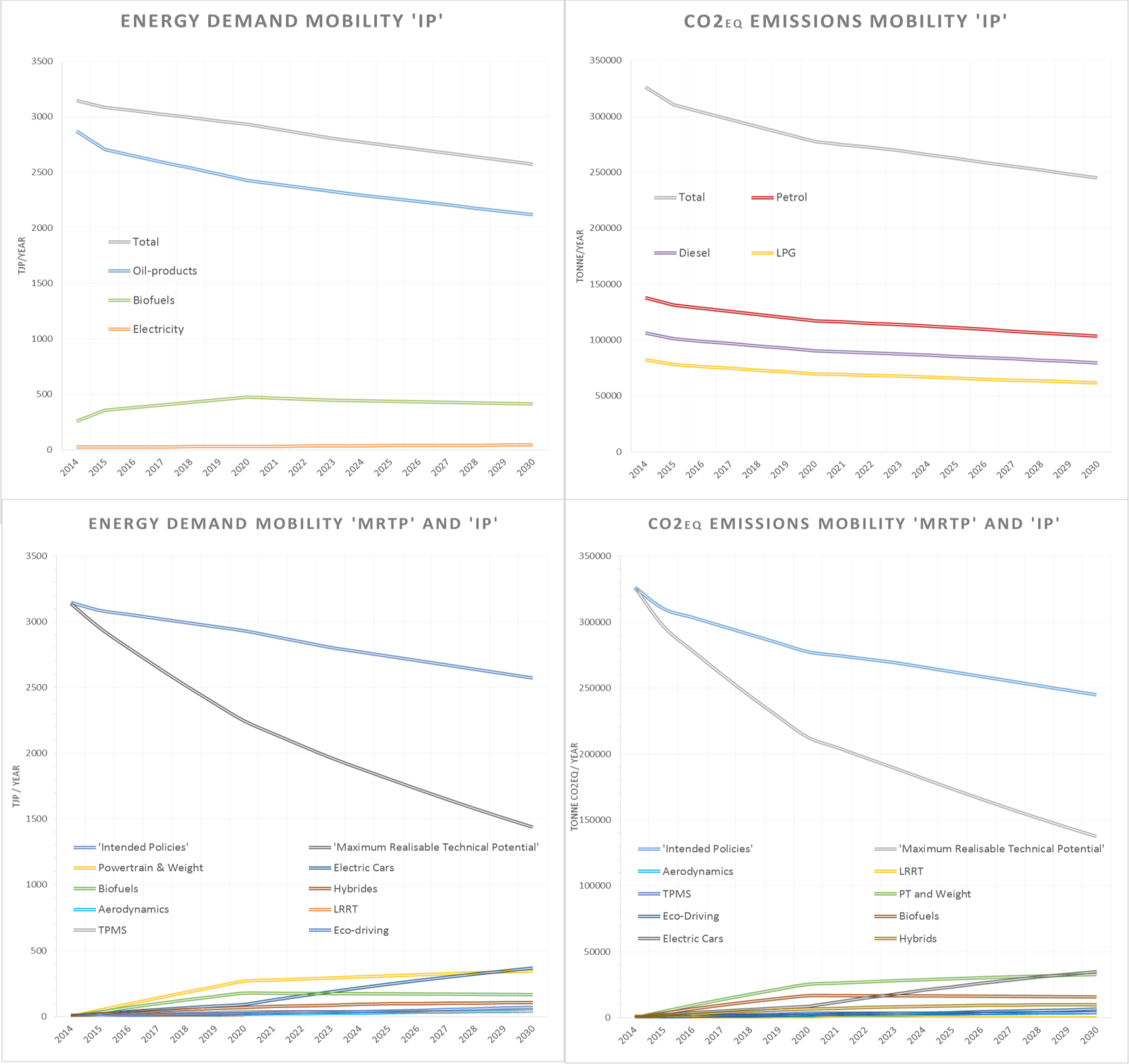


Figure 17 - Energy Demand and CO2eq Emission Projections: Mobility Utrecht

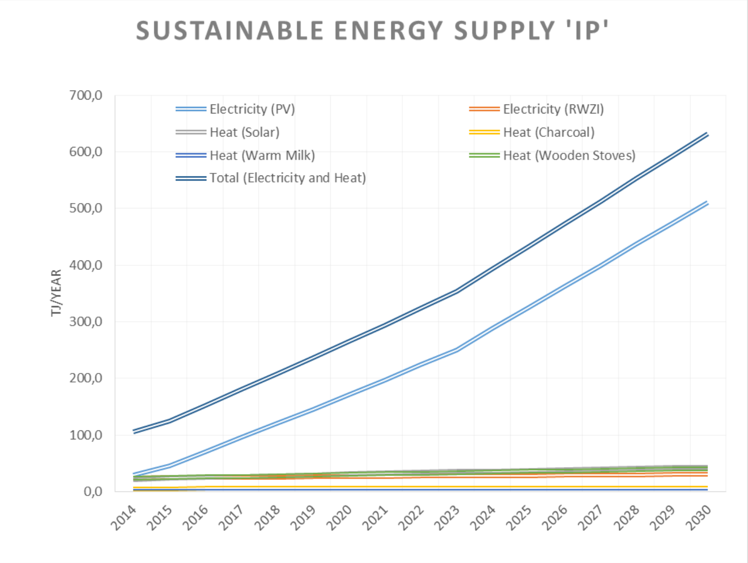
The primary energy demand of the sector mobility in the ‘IP’ scenario decreases from 3,147 TJp to 2,573 TJp. This is constituted by a decrease in oil-products from 2,870 TJp to 2,117 TJp. Biofuels increase their primary energy usage from 255.8 TJp to 412.3 TJp whereas the primary energy supply of electricity related to hybrids and electric vehicles increases from 22.5TJp to 43.9TJp. The associated CO_{2eq} emission drop correspondingly from 326,507 Tonne to 244,880 Tonne. Herein, the increase in the primary energy demand for electricity is insignificant.

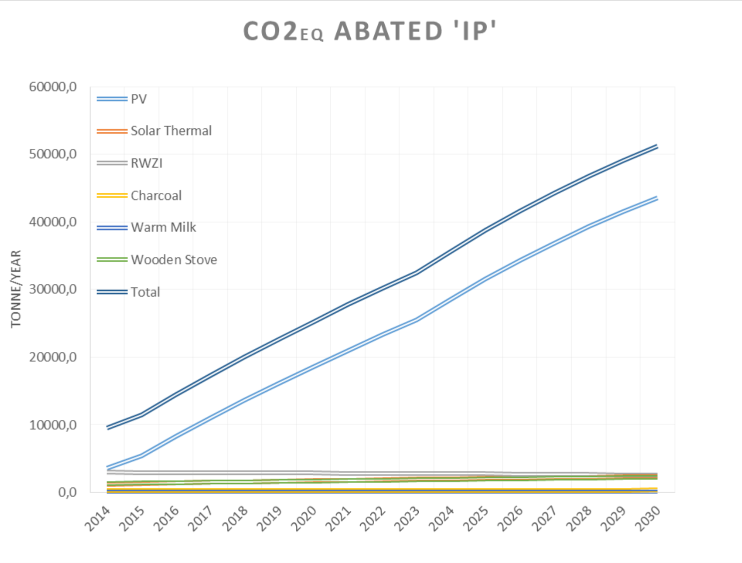
In the ‘MRTP’ scenario the total primary energy demand drops from 3,148 TJp to 1,439 TJp due to numerous efficiency improvements and an increased penetration of hybrid and electric vehicles. Electric cars realise the largest decrease of 368 TJp, closely followed by power train and weight reductions, further decreasing the demand by 345 TJp (the trend related to electric cars is expect to continue, rendering them a very promising prospect with regard to primary energy reduction). Biofuels level off at a reduction of about 166 TJp while the implementation of hybrids accounts for a steadily increasing primary energy demand reduction of 105 TJp in total. The options relating to improved aerodynamics, LRRT, TPMS and eco-driving amount to a cumulative reduction of less than 150 TJp.

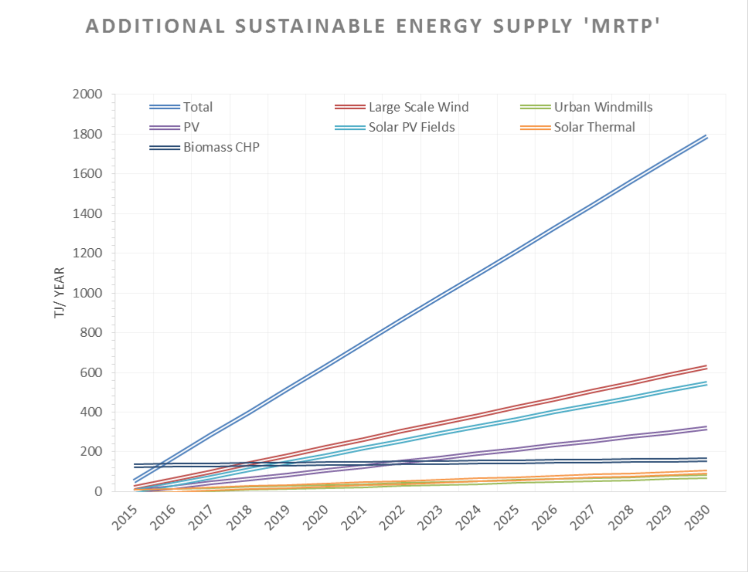
The associated CO_{2eq} emissions in the ‘MRTP’ scenario drop significantly from 326,507 Tonne to 137,452 Tonne. Powertrain and weight reduction measures abate a significant part of 32,811 Tonne by 2030. Biofuels and hybrids negate 1,577 Tonne and 9,992 Tonne respectively, closely followed by Eco-driving (6,430 Tonne) and TPMS (3,755 Tonne). Improved aerodynamics abate approximately 3,673 Tonne, whereas electric cars abate a significant amount of 34,989 Tonne.

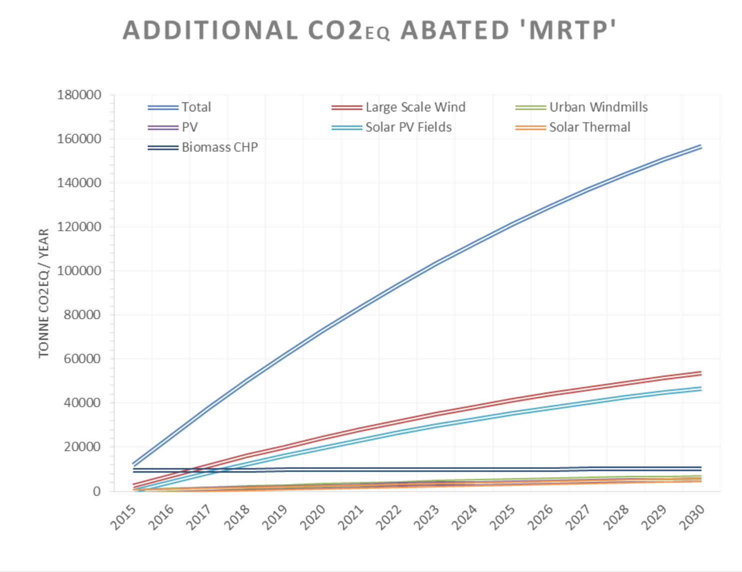
When compared to the ‘IP’ scenario, the ‘MRTP’ scenario reduces total primary energy demand in 2030 from 2,573 TJp to 1,439 TJp (i.e. a 1,143 TJp reduction, or a 44% reduction), whereas the associated CO_{2eq} reduction amounts to 107,428 Tonne (from 244,880 Tonne to 137,452 Tonne; also a 44% reduction).

Utrecht – Renewable Energy Production









The sustainable energy supply in the ‘IP’ scenario increases from 105 TJ to 632 TJ (i.e. 527 TJ) which is predominantly attributed to a rise in additional PV-panels (increasing by 481 TJ from 30 TJ to 511 TJ) and a slight increase in heat supplied via solar thermal boilers (increasing by 21 TJ from 22 TJ to 43 TJ) and wooden stoves (increasing by 16 TJ from 25 TJ to 41 TJ). The other options supply a fairly insignificant amount and are not expected to rise meaningfully within this scenario. The heat supplied through warm milk remains constant at 0.2 TJ whereas the heat supplied through charcoal rises by 1 TJ from 5.3 TJ to 6.3 TJ. The electricity supplied through the RWZI increases by 6 TJ from 24 TJ to 30 TJ.

The associated abated CO_{2eq} increases more drastically from 9,532 Tonne to 51,210 Tonne (effectively abating an additional 41,678 Tonne). This is predominantly caused by the PV-panels producing electricity that is assumed to otherwise be produced in conventional power plants. The abatement through the electricity production via the RWZI decreases from 2,995 Tonne to 2,631 Tonne (i.e. by 364 Tonne) due to decreasing carbon intensities in conventional power production offsetting the small increase in collected waste as a function of projected population growth. Abatement through wooden stoves increases from 1,350 Tonne to 2,259 Tonne (i.e. 909 Tonne) and abatement through solar thermal systems is expected to increase from 1,219 Tonne to 2,407 Tonne (i.e. 1,188 Tonne). The abatement through heat derived out of warm milk and charcoal burning remain fairly constant with charcoal abatement rising from 298 Tonne to 353 Tonne (i.e. 55 Tonne) and warm milk abatement decreasing from 11.3 Tonne to 11.1 Tonne (i.e. 0.2 Tonne).

Regarding the additional production of sustainable energy in the ‘MRTP’ scenario, Utrecht can potentially produce a grand total of 1,791 TJ in 2030. The largest contribution comes from the implementation of large scale wind turbines, supplying 627 TJ by 2030. These are closely followed by PV-fields, potentially delivering 546 TJ. Additional PV-panels could supply 318 TJ, whereas the biomass CHP power plant could deliver 160 TJ and the RWZI could provide for 30 TJ. Finally, solar thermal systems could supply 97 TJ and the instalment of urban windmills could deliver 75 TJ by 2030.

The associated additional CO_{2eq} that is abated in the ‘MRTP’ scenario amounts to 156,607 Tonne by 2030. Similar to the respective contributions to the projected additional energy supply, the largest contribution comes from the large scale wind turbines, potentially abating 53,523 Tonne. This is closely followed by 46,608 Tonnes that are abated through solar PV fields. The biomass CHP power plant could potentially abate 10,079 Tonne, followed by the abatement potential of 6,400 Tonne through urban windmills. Finally, solar thermal heat potentially abates 5,403 Tonne and PV-panels abate 5,279 Tonne.

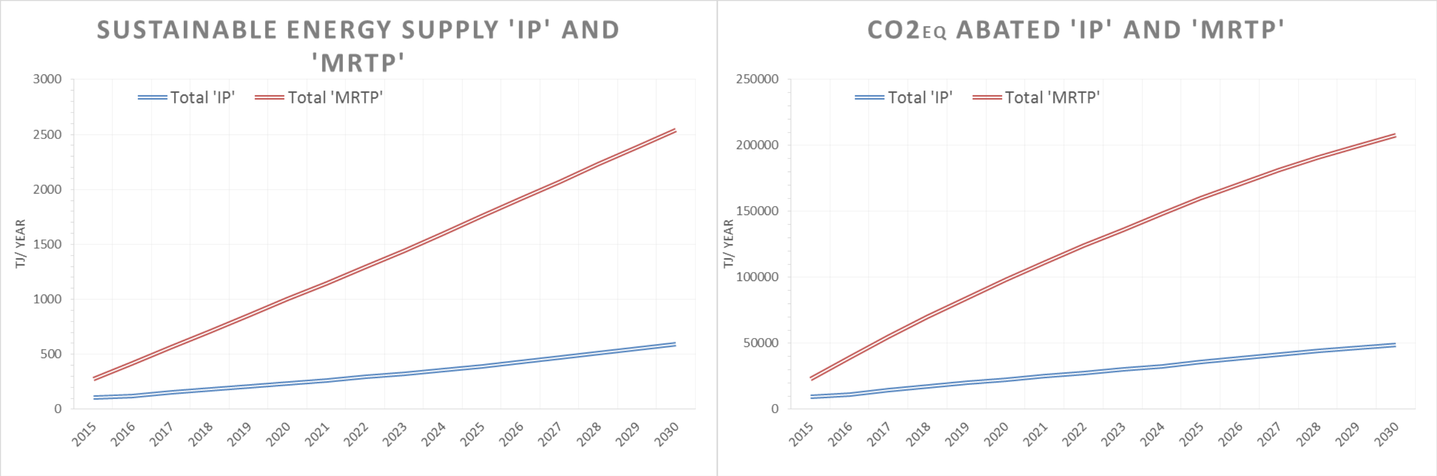


Figure 19 - Comparison of 'IP' and 'MRTP' Projections in Sustainable Energy Supply and Associated CO2e Emissions in Utrecht in 2030

Comparing the ‘IP’ and ‘MRTP’ scenarios in terms of total additional sustainable energy supplied, by 2030 the ‘IP’ scenario would deliver 692 TJ whilst the ‘MRTP’ scenario would produce 2,543 TJ, or roughly 3.7 times the energy produced in the ‘IP’ scenario. This is reflected in the projected abated CO_{2eq} where in the ‘IP’ scenario 49,066 Tonne are abated in 2030, whilst this amounts to 207,816 Tonne in the ‘MRTP’ scenario (i.e. 4.2 fold increased abatement potential).

Utrecht – Associated Costs and Comparisons

Figure 20 - Projected Cumulative Additional Costs for the 'MRTP' Projections related to Energy Efficiency & Renewable Energy Options for Utrecht

The total cumulative additional costs related to the projected energy-efficiency options for Utrecht in 2030 amount to 4,492 million euros. 2,244 million hereof is associated with these efficiency improvements in the sector households (i.e. renovating and the construction of new, more energy-efficient, housing). Analysed options relating to the service sector are expected to cost 2,061 million, followed by the mobility sector amounting to cumulative costs of 183 million euros. Finally, the costs related to the agricultural sector amount to 4 million whilst those related to the industry and energy sector are framed at zero euros (see chapter 3.7.1).

The total cumulative costs associated with the projected renewable energy options for Utrecht in 2030 amount to 668 Million euros. The largest part of this (i.e. 186 million or 28%) is attributed to the costs associated with the development of PV systems, closely followed by urban windmills (167 million or 25%) and solar PV fields (160 million or 24%). Costs associated with large scale wind turbine development amount to 107 million. The lowest cumulative additional costs are coupled with the implementation of solar thermal systems and amount to 48 million.

The projected energy-efficiency and renewable energy production options in the 'MRTP' scenario are ordered and presented below in Table LI regarding the energy-efficiency options and Table LII relating to the renewable energy options. The data is reflective of the additional energy saved, CO_{2eq} abated and associated costs in the 'MRTP' scenario as compared to the 'IP' reference scenario. This data is ordered and numbered in order to reflect the order of contribution of the respective energy-efficiency and renewable energy options.

Organised Contribution of Projected Energy-efficiency Options, Associated CO2eq Abated and Associated Cumulative Costs in 2030					
Energy-efficiency Option		Associated CO_{2eq} Abated		Associated Costs	
Sector	Energy Saved (TJp)	Sector	CO_{2eq} Abated (Tonne)	Sector	Cumulative Costs (Million Euro)
1. Households	4,601	1. Services	122,138	1. Households	2,244
2. Services	2,976	2. Mobility	107,428	2. Services	2,061
3. Mobility	1,122	3. Households	54,567	3. Mobility	183
4. Industry	617	4. Industry	26,238	4. Agriculture	4
5. Agriculture	15	5. Agriculture	3,387	5. Industry	0
Total	9,330	Total	313,759	Total	4,492

Table LI - Organised Contribution of Projected Energy-efficiency Options and Associated CO2eq Abated and Cumulative Costs for Utrecht in 2030

When organised according to the amount of primary energy saved, the sector households is expected to save 4,601 TJp (or 49% of the total) in the 'MRTP' scenario when compared to the 'IP' scenario. The service sector can potentially save about 2,976 TJp (or 32%) through energy-efficiency improvements. The mobility sector saves about one third the amount of energy of the service sector at 1,122 TJp (or 12%) saved, followed by 617 TJp (approx. 7%) saved through improvements in the industry and energy sector. The potential energy saved in the agricultural sector is fairly insignificant, amounting to 15 TJp (approx. 0.2%) saved.

Distributed by associated CO_{2eq} abated, the service sector can potentially abated the largest amount (i.e. 122,138 Tonne or 39%), closely followed by the mobility sector (107,428 Tonne or 34%) and the sector households (54,567 Tonne or 17%). The relatively low position of the sector households when compared to the aforementioned potential primary energy saved is explained through a relatively small drop in electricity demand (which is converted to the required primary energy demanded) when compared to the service sector and a shift away from conventional fuels in the mobility sector. These have a limited effect on the total primary energy saved but a large effect on the associated abated CO_{2eq} through lowered emission factors and sustainable fuels. The slightly larger (though proportional) amount of CO_{2eq} is abated through developments in the industry and energy sector (i.e. 26,238 Tonne or 8%) when compared to the amount of energy saved. Finally, the proportionally large abatement potential of the agricultural sector (i.e. 3,387 Tonne or 1%) is largely attributed to developments reducing the emitted CH_4 and N_2O which are released as a consequence of agricultural practices that are not (directly) related to energy usage.

When contrasted with the associated costs, energy-efficiency improvements in the sector households are relatively expensive at 2,244 million euro (or 50% of the total costs). The service sector is the second most costly option (at 2,061 million or 46%) but does deliver the second highest potentials in terms of energy savings and the highest CO_{2eq} abatement potential; rendering it a more viable sector than the sector households in terms of abatement potential and costs but less viable in terms of primary energy saved. The costs associated with the mobility sector are fairly low (i.e. 183 million or 4% of the total costs) whereas especially the related abated CO_{2eq} is large, almost of the same magnitude as the service sector. Effectively, energy-efficiency improvements in the mobility sector can greatly reduce CO_{2eq} emissions against relatively low costs. To a lesser extend this holds for the agricultural sector as well; abating a relatively large amount of CO_{2eq} (when compared to the associated primary energy saved and the costs) against a fraction of the potential total costs (i.e. 4 million or almost 0.1%). These agricultural developments are thus very cost-efficient, yet they have a limited absolute impact when compared to the aforementioned sectors. Finally, the industrial sector improvements are assumed to not entail any costs (see chapter 3.7.1.) rendering them highly cost-efficient. However, the associated energy saving is relatively low, effectively limiting the absolute impact hereof on the energy system of Utrecht.

Organised Contribution of Projected Renewable Energy Production Options and Associated CO2eq Abated and Cumulative Costs in 2030					
Renewable Energy Option		Associated CO_{2eq} Abated		Associated Costs	
RES Option	Energy Produced (TJ)	RES Option	CO_{2eq} Abated (Tonne)	Sector	Cumulative Costs (Million Euro)
1. Large Scale Wind	627	1. Large Scale Wind	53,524	1. PV panels	186
2. PV fields	546	2. PV fields	46,608	2. Urban windmills	167
3. PV panels	405	3. PV panels	34,593	3. PV fields	160
4. Biomass CHP plant	160	4. Biomass CHP plant	10,079	4. Large scale wind	107
5. Solar thermal	97	5. Urban windmills	6,400	5. Solar thermal	48
6. Urban windmills	75	6. Solar thermal	3,039	6. Biomass CHP plant	0
7. RWZI (biogas)	0	7. RWZI (biogas)	0	7. RWZI (biogas)	0
8. Charcoal burning	0	8. Charcoal burning	0	8. Charcoal burning	0
9. Warm milk	0	9. Warm milk	0	9. Warm milk	0
10. Wooden stoves	0	10. Wooden stoves	0	10. Wooden stoves	0
Total	1,911	Total	154,243	Total	668

Table LII - Organised Contribution of Projected Renewable Energy Production Options and Associated CO2eq Abated and Cumulative costs for Utrecht in 2030

In terms of renewable energy produced, large scale wind turbines contribute the most (almost 33% of the total). This is reflected in the associated CO_{2eq} abated (approx. 35%). The associated costs however, are fairly low (approx. 16%) rendering large scale wind a very viable option across the board. PV field systems are the second biggest contributor in terms of both renewable energy produced (approx. 29% of the total) and associated CO_{2eq} abated (approx. 30%) against relatively higher costs (approx. 24%) than the large scale wind turbines. PV panels have the highest relative costs (approx. 28%) against disproportionately low contributions in renewable energy produced (approx. 21%) and associated CO_{2eq} abated (approx. 22%). The costs of the biomass CHP plant are unknown but its contribution in terms of energy supply and abatement potential is fairly limited when compared to the other identified options (excluding solar thermal systems). Accounting for about 8% of renewable energy produced and 7% of the abatement potential. The solar thermal systems contribute about 5% in terms of renewable energy supply and about 2% in terms of abated CO_{2eq} whilst accounting for approx. 7% of the total costs; rendering it one of the less viable renewable energy options in terms of renewable energy production, CO_{2eq} abatement and associated costs. Finally, urban windmills deliver about 4% of total sustainable energy produced and CO_{2eq} abated but against almost 25% of the costs, rendering it the least financially viable option for De Bilt in 2030 according to the 'MRTP' scenario as compared to the 'IP' scenario.

Additional cumulative costs relating to the RWZI (biogas derived out of sewage), charcoal burning, heat from warm milk and wooden stoves are framed at zero since herein there is no assumed difference between the 'IP' (i.e. reference) and 'MRTP' scenario.

CONCLUSION

The main goal of this research has been to determine the maximum realisable technical potentials and associated costs of the energy systems of De Bilt and Utrecht, aimed at achieving municipal energy neutrality by 2030. As a starting point, relevant energy and GHG emission data has been selected out of the Dutch national database the KlimaatMonitor, grouped according to the following main sectors: Households, services, industry, agriculture and mobility (i.e. transport). National 'intended policies' projections related to these sectors have been derived out of the Dutch 'Nationale Energieverkenning' and have subsequently been applied to the gathered data; effectively forming a 'reference' pathway or scenario. Consequently, maximum realisable technical potentials relating to energy-efficiency options and sustainable energy production opportunities and their associated costs have been identified and were applied to the gathered data, thereby effectively forming the maximum realisable technical potential or 'MRTP' scenarios for both municipalities which are contrasted with the aforementioned reference 'IP' scenarios.

With respect to the municipality of Utrecht, a maximum realisable technical potential relating to energy efficiency options has been determined to entail a domestic primary energy demand of 9,659 TJp and associated CO_{2eq} emissions of 659,332 Tonne by 2030. When compared to the reference 'IP' scenario (18,989 TJp and 973,091 Tonne CO_{2eq} emitted) this entails a reduction of 9,330 TJp with an associated 313,759 Tonne of additionally avoided CO_{2eq} emissions. An additional 1,911 TJ of renewable energy is produced in the 'MRTP' scenario (whereas this amount to 601 TJ in the reference scenario) and an associated additional 154,243 Tonne of CO_{2eq} has been abated. As a consequence the municipality of Utrecht could produce roughly a quarter of its projected domestic primary energy requirements; effectively a twenty-four fold increase with respect to 2014 levels but not enough to achieve domestic energy-neutrality by 2030. The biggest contribution for sustainable energy comes from PV-systems, delivering 916 TJ and abating 78,180 Tonne CO_{2eq}. The total abatement potential comes down to 205,453 Tonne of CO_{2eq}; effectively a twenty-one fold increase over 2014 levels.

Total cumulative additional costs for Utrecht are projected to amount to 4,492 million euros concerning the implementation of identified energy-efficiency options (wherein the sector households and the sector services account for 2,244 and 2,061 million respectively whilst the agricultural costs only amount to 4 million), and 668 million euros with respect to the development of renewable energy production options (of which PV panels constitute the highest costs at 186 million and the lowest costs are connected to the implementation of solar thermal systems at 48 million). Energy-efficiency improvements save the largest amount of primary energy in the sector households, whilst those related to the service sector have the highest abatement potential, closely followed by efficiency improvements in the mobility sector. Improvements in the mobility sector are found to greatly reduce CO_{2eq} emissions against relatively low costs. To a lesser extend this holds for the agricultural and industrial sector as well, which have low costs but also fairly limited reduction potentials.

In terms of renewable energy produced and associated CO_{2eq} abated, large scale wind turbines contribute the largest amount, generating 627 TJ (33% of total) and abating 53,524 Tonne (35% of total). The associated costs are fairly low at 107 million (16% of total costs) rendering it the most viable option, followed by PV field systems which are fairly comparable but against higher additional costs. Urban windmills and solar thermal systems are the least contributing options in terms of primary energy saved and CO_{2eq} abated and while solar thermal systems are relatively inexpensive (7% of total costs), urban windmills account for about 25% of total costs, rendering it the least viable option in terms of additional costs.

With respect to the municipality of De Bilt, the maximum realisable technical potential relating to energy efficiency options as been framed at a domestic primary energy demand of 2,201 TJp by 2030. Compared to the reference scenario of 3,022 TJp this implies a reduction of 821 TJp with an associated 46,224 Tonne of additionally avoided CO_{2eq} emissions (177,002 Tonne in the 'IP' reference scenario). Furthermore, an additional 5,673 TJ of renewable energy is produced when compared to this reference scenario (producing 156 TJ by 2030) and an associated 508,826 Tonne of CO_{2eq} has been abated (in the 'IP' reference this abatement amounts to 11,047 Tonne). Especially due to the developments of solar PV-fields, De Bilt has the potential to produce roughly three times its own projected domestic primary energy requirement by 2030 and can therefore be classified as an energy-neutral municipality, producing over 90 times the amount of renewable energy as it did in 2014 and abating 130 times as much CO_{2eq}. In theory, though outside the current scope, this excess in sustainably produced energy could even support the neighbouring municipality of Utrecht, potentially abating half of their remaining projected CO_{2eq} emissions by 2030.

Total cumulative additional costs are estimated to amount to 879 million euro relating to energy-efficiency improvements and 1,747 million as a consequence of domestic renewable energy production developments. Within the energy-efficiency measures, improvements in the sector households yield the highest costs at 451 million (approx. 51%), followed by the service sector at 319 million (or 36%) and the mobility sector at 102 million (or 12%) and finally the agricultural sector at 7 million (approx. 0.8%). These energy-efficiency improvements save the largest amount of primary energy in the service sector (in contrast to Utrecht, where this is the household sector) and abate the largest amount of CO_{2eq} (similar to Utrecht) against reasonable costs. As in Utrecht, improvements in the mobility sector are found to greatly reduce CO_{2eq} emissions against relatively low costs. To a lesser extend this holds for the agricultural and industrial sector as well, which have low costs but also fairly limited reduction potentials.

In terms of renewable energy produced and associated CO_{2eq} abated, PV-fields contribute the largest amount by far, generating 5,080 TJ (almost 90% of total) and abating 457,209 Tonne (90% of total). The associated costs are correspondingly high at 1,486 million (85% of total costs) rendering it the most viable option in terms of energy produced and CO_{2eq} abated but against high costs. Large scale wind turbines generate about 418 TJ (approx. 7% of the total) and abate a related 37,638 Tonne (or 7%) against relatively lower costs (at 71 million or 4% of the total) making it one of the more viable options in financial terms. PV panels have a limited potential in terms of energy produced (61 TJ or 1%) and CO_{2eq} abated (5,513 Tonne or 0.9%) but have fairly high associated costs at 29 million euro (approx. 1.7%) rendering them less interesting. Urban windmills, the biomass CHP plant and solar thermal systems are the least contributing options in terms of primary energy saved and CO_{2eq} abated. While solar thermal systems are relatively expensive (2.7% of total costs at 48 million) they have the lowest contribution in terms of energy saved and abatement potential, rendering them amongst the less feasible options. Similarly, urban windmills account for about 6% of total costs at 113 million whilst accounting for limited energy production and CO_{2eq} abatement.

Based on the assumptions made, the municipality of De Bilt thus has the potential for achieving domestic energy-neutrality in 2030 whereas the Municipality of Utrecht does not. It is deemed imperative that both the energy-efficiency options and the identified renewable energy options are implemented in unison. With the exception of the PV-field systems in De Bilt, generally, energy-efficiency options are the most effective in terms of primary energy saved and associated CO_{2eq} abated but they are generally more expensive than options focussing on domestic sustainable energy production. Herein, large scale wind turbines and PV-fields are the most feasible options in both municipalities, whereas urban windmills and solar thermal systems are less sensible. Since costs for the biomass CHP plant are unknown, it is not directly compared with the other options in terms of costs and feasibility. Due to the complex nature and interactions related to such an analysis, it is reiterated that the results should be viewed as indicative of general developments and requirements related to the development of the municipal energy-systems.

First-off, the quality of this data is influenced by multiple factors, such as: The accuracy of measurements, the level of inclusiveness and the applicability, integrity, consistency and robustness of the data, methods, conversions and calculations used. With respect to the gathered data from KlimaatMonitor, for the so-called individual 'point sources' this uncertainty is predominantly depended on the methodological prowess of the respective ER-I sources, as well as that of the respective controlling bodies (provinces, municipalities, waterboards and licensing institutions). However, through lack of detailed data provided in environmental reports, relatively large uncertainties can arise.

With respect to the model-based and distribution-key calculated data derived out of the klimaatmonitor, potentially significant uncertainties can arise due to the generic fashion in which this 'proxy-data' is determined. Furthermore, not every model and distribution key can be updated annually, implying less accurate annual municipal data when compared to the national aggregated data. Luckily, a number of controls have been integrated. With respect to the quality of the data used, this is subjected to continues inventorying and classification hereof, which is propounded by the European Environmental Agency (EEA) and conforms to the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (EEA, 2013). Furthermore, an important controlling step is embodied by a trend analysis wherein the current estimated data from a specific source is compared to known emissions data from previous years for that specific source or. Three studies have conducted research on Dutch GHG-emissions and air-pollution wherein the influence of said factors is amalgamated into uncertainty-ranges (Neelis & Blinde, 2010; Olivier et al., 2009; Ramírez et al., 2006). An overview of the main findings is presented in Table LIVIV of the appendix. The uncertainty margin for CO_2 has been determined to fall within a couple of percent whereas the uncertainty margin for the other GHG emissions are much larger implying relatively low reliability regarding the agricultural sector.

Furthermore, the identified 'IP' and 'MRTP' scenarios and their associated key-indicators and accompanying costs are also subjected to uncertainties. The input data supplied through these sources is selected from recognized sources in order to achieve the highest degree of robustness and reliability possible. In this fashion, the data utilized in the 'IP' scenario is directly derived out of publications from the ECN. It includes the established and those intended European and Dutch policies (including those incorporated in the 'Energieakkoord') that are deemed sufficiently concrete as of May 2014 and these expected developments are taken at face value and any assessment of them is deemed beyond the range of the current research. Additional uncertainties arise, however, when these national projections are adapted to the municipal level and all regionalized data should therefore predominantly be viewed as being indicative and in-depth studies are required in order to achieve a more holistic and specified picture with respect to the municipalities studied. Furthermore, in this 'IP' scenario it is assumed that no new renewable energy production options are introduced other than those already established at present, whilst this may not reflect the actual developments of the energy-systems.

Regarding the 'MRTP' scenario, key indicators have been selected out of publications issued by internationally recognized institutions. The SERPEC-CC studies, for instance, supplied data which was derived out of research conduct by e.g. Ecofys Netherlands, CE-Delft and the Institute of Communication and Computer Systems of the National Technical University of Athens. The scope of these studies is European and, as stated before, substantial uncertainties may arise when these projections are projected onto the municipal level and results should be viewed as indicative. Additionally, in this 'MRTP' scenario it is assumed that no new renewable energy or energy-efficiency options are introduced other than those analysed in this study. These options are assumed to be implemented in a linear fashion until 2030 though actual implementation rates might not fit this linearly projected development. Furthermore, potential new technologies or any break-through herein, for instance in driving down the costs, are not taken into account. The potentially limiting influence of the projected costs is not taken into account and should be studied more in depth, specifically in terms of associated risks and possible financial boundaries to implementation.

As an additional point, in this study, relevant socio-political aspects have been omitted. However, when combined with complementary conclusions such as those derived from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004) (Verbong & Geels, 2007), an analysis of Dutch green electricity policy decisions (van Rooijen & van Wees, 2006) and a meaningful study of energy policy transition in the Netherlands (Kern & Smith, 2008); a more holistic picture of those developments required for establishing municipal energy-neutrality by 2030 can be established. In relation to this, special attention is directed towards the applicability of solar PV-field as applied in the MRTP scenario for De Bilt in which 70% of the forest and rural area is converted into solar PV-field. It is deemed likely that this 70% is highly ambitious and will result in strong opposition from local inhabitants.

When comparing the results to those achieved by the studies conducted by Oude Lohuis et al. (2015) and Benner and Warringa (2012) no large discrepancies arise and a similar 'gap' between the intended goal of achieving municipal energy-neutrality by 2030 and the actual implementation hereof (both at present and projected into the future), in terms of actual renewable energy produced and CO_{2eq} abated, is identified. A significant contrast is identified, however, when comparing the results of De Bilt with the indicative results provided by Gerdes & van Zuijlen (2015) who performed a similar study focussing on the potential for energy-neutrality in the municipality of Enschede. This difference is attributed to the large area that can be allocated to PV-fields in De Bilt when compared to Enschede.

Finally, the practical and societal contribution of this thesis relate to the actual implementation of domestic energy-efficiency and renewable energy production options directly affecting the overall development of these municipalities and their inhabitants. Furthermore, due to the projected environmental benefits, implementation of these options will (indirectly) contribute to the goals of keeping global average temperature change below 2 degrees Celsius and further strengthen the scientific literature regarding sustainable developments (specifically in local governments) and can shake up policy makers who might be unaware of the required effort in order to achieve domestic energy-neutrality by 2030.

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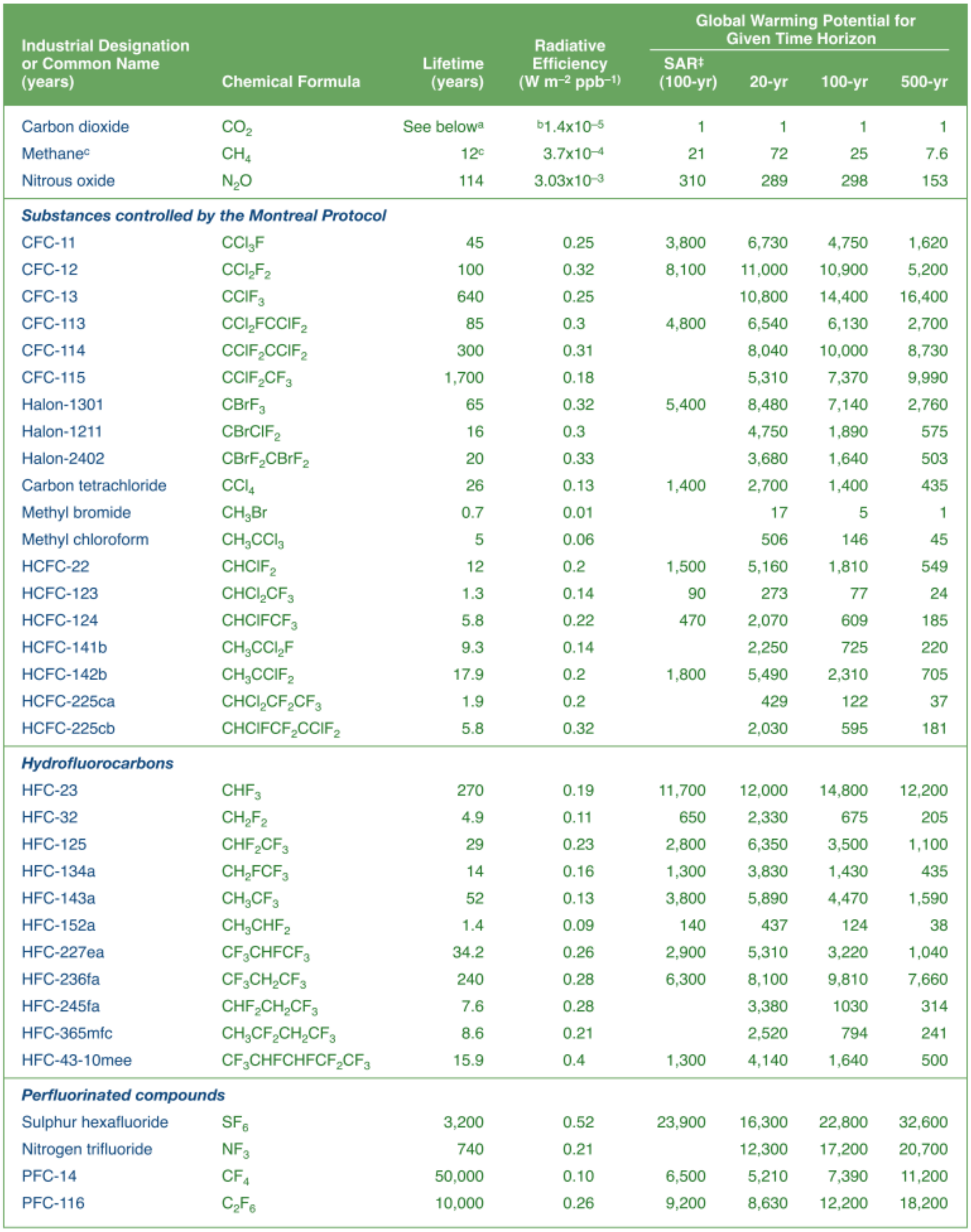
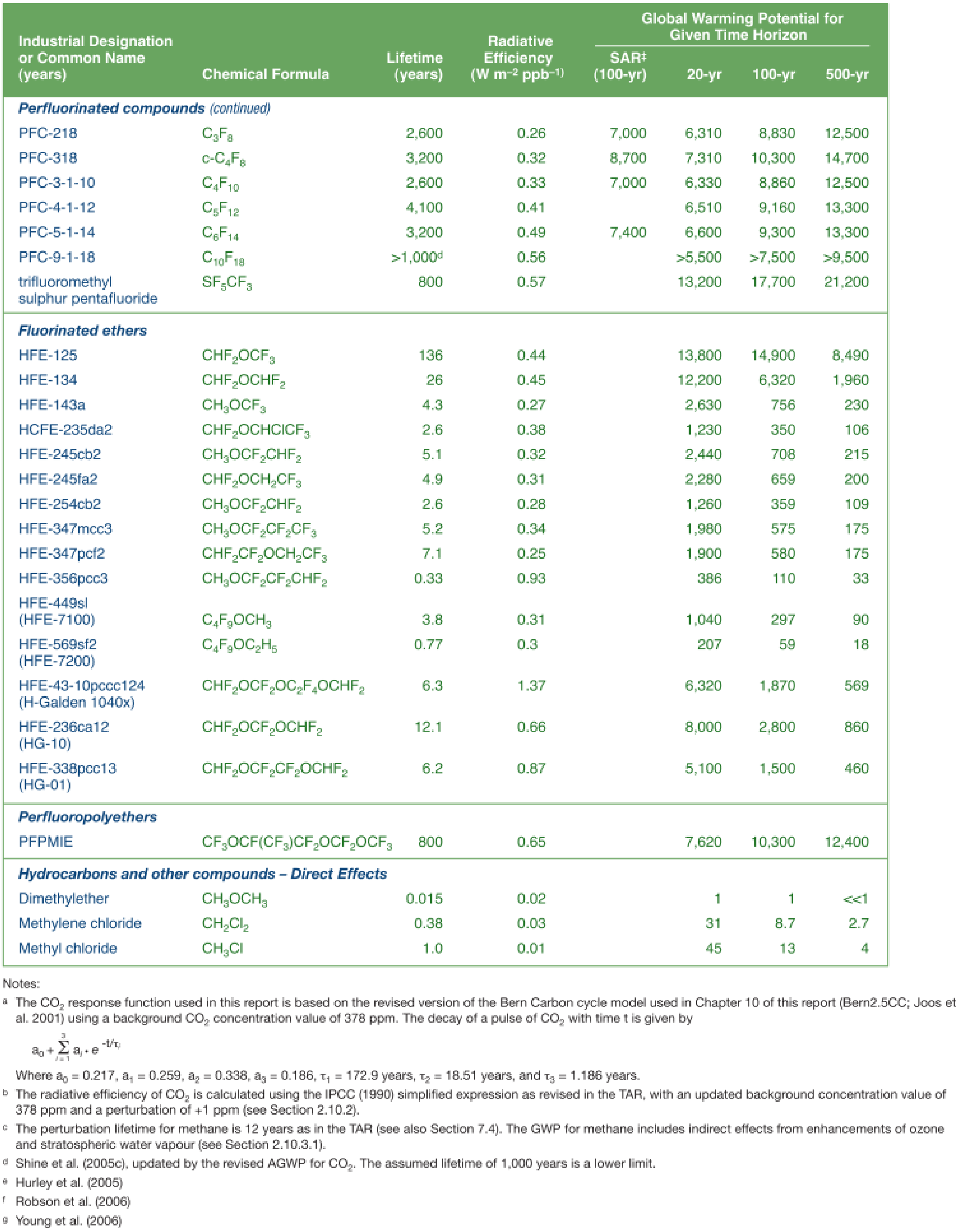
5 APPENDIX

GHG substances and associated global warming potential



Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency (W m^{-2} ppb^{-1})	Global Warming Potential for Given Time Horizon			
				SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b]$1.4x10^{-5}$	1	1	1	1
Methane[c]	CH_4	12[c]	$3.7x10^{-4}$	21	72	25	7.6
Nitrous oxide	N_2O	114	$3.03x10^{-3}$	310	289	298	153
Substances controlled by the Montreal Protocol							
CFC-11	CCl_3F	45	0.25	3,800	6,730	4,750	1,620
CFC-12	CCl_2F_2	100	0.32	8,100	11,000	10,900	5,200
CFC-13	$CClF_3$	640	0.25		10,800	14,400	16,400
CFC-113	CCl_2FCClF_2	85	0.3	4,800	6,540	6,130	2,700
CFC-114	$CClF_2CClF_2$	300	0.31		8,040	10,000	8,730
CFC-115	$CClF_2CF_3$	1,700	0.18		5,310	7,370	9,990
Halon-1301	$CBrF_3$	65	0.32	5,400	8,480	7,140	2,760
Halon-1211	$CBrClF_2$	16	0.3		4,750	1,890	575
Halon-2402	$CBrF_2CBrF_2$	20	0.33		3,680	1,640	503
Carbon tetrachloride	CCl_4	26	0.13	1,400	2,700	1,400	435
Methyl bromide	CH_3Br	0.7	0.01		17	5	1
Methyl chloroform	CH_3CCl_3	5	0.06		506	146	45
HCFC-22	$CHClF_2$	12	0.2	1,500	5,160	1,810	549
HCFC-123	$CHCl_2CF_3$	1.3	0.14	90	273	77	24
HCFC-124	$CHClFCF_3$	5.8	0.22	470	2,070	609	185
HCFC-141b	CH_3CCl_2F	9.3	0.14		2,250	725	220
HCFC-142b	CH_3CClF_2	17.9	0.2	1,800	5,490	2,310	705
HCFC-225ca	$CHCl_2CF_2CF_3$	1.9	0.2		429	122	37
HCFC-225cb	$CHClFCF_2CClF_2$	5.8	0.32		2,030	595	181
Hydrofluorocarbons							
HFC-23	CHF_3	270	0.19	11,700	12,000	14,800	12,200
HFC-32	CH_2F_2	4.9	0.11	650	2,330	675	205
HFC-125	CHF_2CF_3	29	0.23	2,800	6,350	3,500	1,100
HFC-134a	CH_2FCF_3	14	0.16	1,300	3,830	1,430	435
HFC-143a	CH_3CF_3	52	0.13	3,800	5,890	4,470	1,590
HFC-152a	CH_3CHF_2	1.4	0.09	140	437	124	38
HFC-227ea	CF_3CHFCF_3	34.2	0.26	2,900	5,310	3,220	1,040
HFC-236fa	$CF_3CH_2CF_3$	240	0.28	6,300	8,100	9,810	7,660
HFC-245fa	$CHF_2CH_2CF_3$	7.6	0.28		3,380	1030	314
HFC-365mfc	$CH_3CF_2CH_2CF_3$	8.6	0.21		2,520	794	241
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	15.9	0.4	1,300	4,140	1,640	500
Perfluorinated compounds							
Sulphur hexafluoride	SF_6	3,200	0.52	23,900	16,300	22,800	32,600
Nitrogen trifluoride	NF_3	740	0.21		12,300	17,200	20,700
PFC-14	CF_4	50,000	0.10	6,500	5,210	7,390	11,200
PFC-116	C_2F_6	10,000	0.26	9,200	8,630	12,200	18,200



Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency (W m^{-2} ppb^{-1})	Global Warming Potential for Given Time Horizon			
				SAR‡ (100-yr)	20-yr	100-yr	500-yr
Perfluorinated compounds *(continued)*							
PFC-218	C_3F_8	2,600	0.26	7,000	6,310	8,830	12,500
PFC-318	$c\text{-}C_4F_8$	3,200	0.32	8,700	7,310	10,300	14,700
PFC-3-1-10	C_4F_{10}	2,600	0.33	7,000	6,330	8,860	12,500
PFC-4-1-12	C_5F_{12}	4,100	0.41		6,510	9,160	13,300
PFC-5-1-14	C_6F_{14}	3,200	0.49	7,400	6,600	9,300	13,300
PFC-9-1-18	$C_{10}F_{18}$	>1,000[d]	0.56		>5,500	>7,500	>9,500
trifluoromethyl sulphur pentafluoride	SF_5CF_3	800	0.57		13,200	17,700	21,200
Fluorinated ethers							
HFE-125	CHF_2OCF_3	136	0.44		13,800	14,900	8,490
HFE-134	CHF_2OCHF_2	26	0.45		12,200	6,320	1,960
HFE-143a	CH_3OCF_3	4.3	0.27		2,630	756	230
HCFE-235da2	$CHF_2OCHClCF_3$	2.6	0.38		1,230	350	106
HFE-245cb2	$CH_3OCF_2CHF_2$	5.1	0.32		2,440	708	215
HFE-245fa2	$CHF_2OCH_2CF_3$	4.9	0.31		2,280	659	200
HFE-254cb2	$CH_3OCF_2CHF_2$	2.6	0.28		1,260	359	109
HFE-347mcc3	$CH_3OCF_2CF_2CF_3$	5.2	0.34		1,980	575	175
HFE-347pcf2	$CHF_2CF_2OCH_2CF_3$	7.1	0.25		1,900	580	175
HFE-356pcc3	$CH_3OCF_2CF_2CHF_2$	0.33	0.93		386	110	33
HFE-449sl (HFE-7100)	$C_4F_9OCH_3$	3.8	0.31		1,040	297	90
HFE-569sf2 (HFE-7200)	$C_4F_9OC_2H_5$	0.77	0.3		207	59	18
HFE-43-10pccc124 (H-Galden 1040x)	$CHF_2OCF_2OC_2F_4OCHF_2$	6.3	1.37		6,320	1,870	569
HFE-236ca12 (HG-10)	$CHF_2OCF_2OCHF_2$	12.1	0.66		8,000	2,800	860
HFE-338pcc13 (HG-01)	$CHF_2OCF_2CF_2OCHF_2$	6.2	0.87		5,100	1,500	460
Perfluoropolyethers							
PFPMIE	$CF_3OCF(CF_3)CF_2OCF_2OCF_3$	800	0.65		7,620	10,300	12,400
Hydrocarbons and other compounds – Direct Effects							
Dimethylether	CH_3OCH_3	0.015	0.02		1	1	<<1
Methylene chloride	CH_2Cl_2	0.38	0.03		31	8.7	2.7
Methyl chloride	CH_3Cl	1.0	0.01		45	13	4

Notes:

[a] The CO_2 response function used in this report is based on the revised version of the Bern Carbon cycle model used in Chapter 10 of this report (Bern2.5CC; Joos et al. 2001) using a background CO_2 concentration value of 378 ppm. The decay of a pulse of CO_2 with time t is given by

$$a_0 + \sum_{i=1}^{3} a_i \cdot e^{-t/\tau_i}$$

Where $a_0 = 0.217$, $a_1 = 0.259$, $a_2 = 0.338$, $a_3 = 0.186$, $\tau_1 = 172.9$ years, $\tau_2 = 18.51$ years, and $\tau_3 = 1.186$ years.

[b] The radiative efficiency of CO_2 is calculated using the IPCC (1990) simplified expression as revised in the TAR, with an updated background concentration value of 378 ppm and a perturbation of +1 ppm (see Section 2.10.2).

[c] The perturbation lifetime for methane is 12 years as in the TAR (see also Section 7.4). The GWP for methane includes indirect effects from enhancements of ozone and stratospheric water vapour (see Section 2.10.3.1).

[d] Shine et al. (2005c), updated by the revised AGWP for CO_2. The assumed lifetime of 1,000 years is a lower limit.

[e] Hurley et al. (2005)

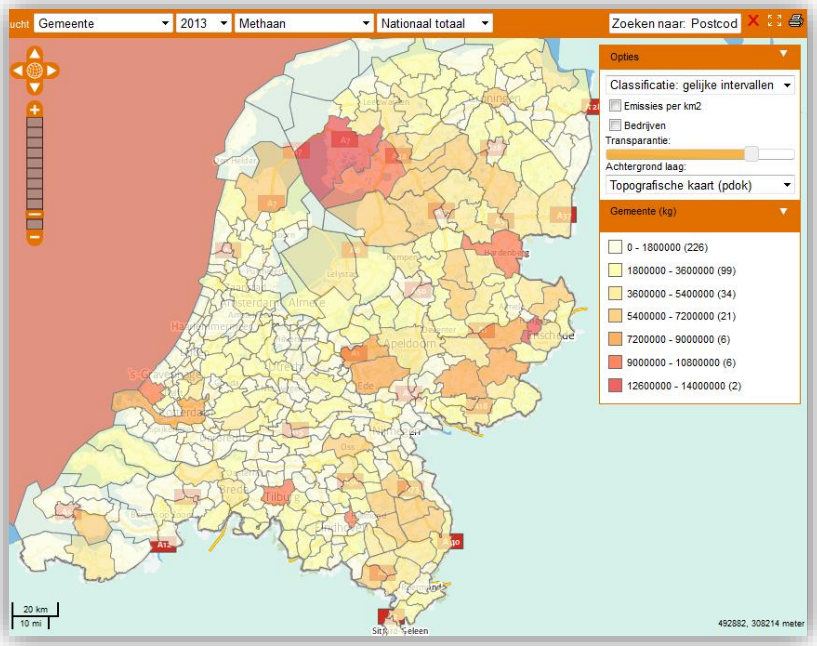
[f] Robson et al. (2006)

[g] Young et al. (2006)

Table LIII -GHG substances and associated global warming potential l(IPCC, 2007)

Dutch Taskforce Spatial Distribution

The Taskforce Spatial Distribution provides emission data for varying geographical scales, ranging from the provincial level to a one by one kilometre grid. It is responsible for the spatial dispersion of GHG-emissions and operates on an annual cycle of emission-registration; additionally supplying emission-factors and emission clarifying variables (Emissieverklarende variable or EVV) such as the amount of kilometres driven or amount of a particular type of waste that is disposed of (often comparable to other types of activity data, though not derived through direct measurements). These results are then made available through the KlimaatMonitor and are also represented graphically on a national and regional level. An example of which is provided for in *Figure 21*.


ucht Gemeente ▾ 2013 ▾ Methaan ▾ Nationaal totaal ▾ Zoeken naar: Postcod

Opties

Classificatie: gelijke intervallen ▾

☐ Emissies per km2

☐ Bedrijven

Transparantie:

Achtergrond laag:

Topografische kaart (pdok) ▾

Gemeente (kg)

- ☐ 0 - 1800000 (226)
- 🟨 1800000 - 3600000 (99)
- 🟨 3600000 - 5400000 (34)
- 🟧 5400000 - 7200000 (21)
- 🟧 7200000 - 9000000 (6)
- 🟥 9000000 - 10800000 (6)
- 🟥 12600000 - 14000000 (2)

Figure 21 - Graphical Representation of CH4-emissions per Municipality 2013 (Derived from KlimaatMonitor)

The methods used for spatial allocation fall into three categories: direct linkage to location, model calculation and estimation through ‘proxy data’. For each of the spatial allocation categories, a factsheet containing a brief description of the methods used, an example of the relevant distribution map, references to background documents and a list of the institutes concerned is provided for via KlimaatMonitor. Herein, firstly, individually reported emissions (MJV) linked to known locations (i.e. point-sources) are supplied via the ER-I database. In addition, data obtained from the CBS concerning a number of substances (e.g. nitrogen and phosphate) in the effluent of sewage treatment plants (RWZIs) and emissions to the air from small airports are supplied as point sources. On a national level, this category encloses almost three thousand sources. Secondly, model calculations are provided for the spatial distribution of: Ammonia from agriculture, particulate matter (PM10) from agriculture (barn emissions), deposition on surface water, leaching and run-off to surface water (heavy metals and nutrients) and emissions from crop protection chemicals to air and surface water. These models are:

1. The NMI model, relating to national environmental indicators for crop protection (Nationale Milieuindicator Gewasbeschermingsmiddelen) as presented by the RIVM (2014a). It involves the Dutch institutions RIVM, Alterra and Deltares and utilizes 2008 as base year
2. The STONE model relating to heavy metals (Samen te Ontwikkelen Nutriënten Emissiemodel) as presented by the RIVM (2014b). It involves the Dutch institutions Alterra and the Directorate for Public Works and Water management and utilizes 2010 as base year
3. The OPS model relating to operational priority substances (Operationele Prioritaire Stoffen) as presented by the RIVM (2014c). It involves the Dutch Organization for applied research (TNO), the National Institute for Public health and the Environment, Deltares and the Directorate for Public Works and Water Management and utilizes 2005 as base year
4. The MAMBO model relating to emissions due to manure and ammonia (Mest en Ammoniakemissie voor Beleidsondersteuning) as presented by the RIVM (2014e). It involves the Dutch institutions LEI and Alterra, utilizing 2010 as base year
5. The LGN model relating emissions due to land usage (Landelijk Grondgebruik Nederland) as presented by the RIVM (2014j). It involves the Dutch institution PBL and utilizes 2006-2007 as base year

Finally, the largest group concerns those emissions for which the distribution is approached by means of an allocation key. These allocations predominantly manners revolve around the following:

1. Allocation keys relating to population and housing densities as presented by the RIVM (2014f). It merges two databases: The key register for addresses and buildings (Basisregistraties Adressen en Gebouwen or BAG) and the registery of companies supplied by the chamber of commerce. It utilizes 2010 as base year
2. Allocation keys relating to livestock densities as presented by the RIVM (2014i) and are based on the NEMA model, with the relevant spatial allocation based on the GIAB database. It involves the Dutch institutions Alterra and LEI and utilizes 2012 as base year
3. Allocation keys relating to vehicle kilometres as presented by the RIVM (2014h). It involves the Dutch institutions RIVM, the Ministry of Infrastructure and the Environment, the Directorate General of Waterways and Public Works and Goudappel Coffeng Traffic Consultant. It utilises 2011 as base year
4. Allocation keys relating to land cover as presented by the RIVM (2014d). It involves the Dutch institutions PBL and the CBS and utilizes 2007-2008 as base year
5. Allocation keys relating to the number of jobs per business as provided by the RIVM (2014g) as solely involved Dutch institution utilizing 2010 as base year

The geographical distribution (and diffusion) of emissions are then derived through linking Geographical Information Systems (GIS) to these point-sources, emission-models and distribution keys.

Herein, for example, the overall population density maps are based on the Key Register for Addresses and Buildings, supplied by the Land Registry Office (Kadaster). This data is then overlaid with a map of municipal boundaries as provided by the Central Bureau of Statistics (CBS) and a one by one kilometre grid cell map; effectively yielding the amount of municipal address coordinates per grid cell (i.e. housing density). When the number of municipal residents is allocated to these address coordinates, it yields the average municipal residents per grid cell (i.e. population density) (RIVM, 2014f). Correspondingly, the geographical distribution of vehicle-kilometres per energy-carrier infers the geographical diffusion of the associated transport emissions. In this manner, a municipal road determined to endure a certain amount of vehicle kilometres is attributed the appropriate amount of emissions associated with said vehicle kilometres (RIVM, 2014h).

It is explicitly noted that certain emission sources may entail multiple such spatial allocations in which case the total emission is spread over the available allocations according to agreements between the PRTR and the Dutch Organization for applied scientific research (TNO) (Taakgroep Ruimtelijke Ordening, 2014). All the connections between emission cause, geographical allocation and related methodological approaches are presented on the website of the KlimaatMonitor in the form of a number of allocation-documents. An excel sheet is presented on the KlimaatMonitor website in which all the included emission-types are linked to their respective allocation-document that contains the relevant methodology applicable to the respective emission-type.

Uncertainties and Estimates in Dutch Geographical Emission Diffusion (KlimaatMonitor)

The taskforce explicitly mentions their constant strive towards utilizing the most optimal and up-to-date data in their quest to deliver a geographical distribution of emissions (and diffusions). With respect to the quality of the data used, an inventory hereof is provided based on the classification system CORINAIR according to the EMEP/EEA Air Pollution Emission Inventory Guidebook (formerly EMEP/CORINAIR). This classification system is propounded by the European Environmental Agency (EEA) and conforms to the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (EEA, 2013). It yields useful insights into the respective methodologies underlying the data and gives an indicative indication of the discerned uncertainties herein. The classification is as follows:

A. Data based on a large number of measurements from representative locations
B. Data based on a number of measurements from a part of the locations deemed representative for the respective sector
C. Data based on a limited number of measurements, supplemented by estimations based on the technical knowledge of the respective processes
D. Data based on a small number of measurements, supplemented by estimations based on assumptions
E. Data based on technical calculations founded on a number of assumptions

The quality of this data is influenced by multiple factors, such as: The accuracy of measurements, the level of inclusiveness and the applicability, integrity, consistency and robustness of the data, methods, conversions and calculations used.

For individual ‘point sources’ the uncertainty is predominantly depended on the methodological prowess of the respective ER-I sources, as well as that of the respective controlling bodies (provinces, municipalities, waterboards and licensing institutions). However, through lack of detailed data provided in MJVs, relatively large uncertainties can arise.

With respect to the model-based and distribution-key derived outcomes, potentially significant uncertainties can arise due to the generic fashion in which this ‘proxy-data’ is determined. Furthermore, not every model and distribution key can be updated annually, implying less accurate annual municipal data when compared to the national aggregated data.

In order to attain the appropriate quality data, a number of controls have been integrated. An important part of which is embodied by a trend analysis wherein the current estimated data from a specific source is compared to known emissions data from previous years for that specific source or, alternatively, compared to other emission trends such as atmospheric concentrations. Should large discrepancies be detected, this potentially leads to apposition of the methods utilized (Olivier et al., 2009).

Moreover, three studies have conducted research on Dutch GHG-emissions and air-pollution wherein the influence of said factors is amalgamated into uncertainty-ranges (expressed in percentages) that fluctuate between relatively small and relatively large uncertainties (Neelis & Blinde, 2010; Olivier et al., 2009; Ramírez et al., 2006). An overview of the main findings is presented in *Table LIV*.

GHG	**Uncertainty margin**	**Tier-level**
CO_2	±3%	1
CH_4	±25%	1
N_2O	±50%	1
F-gasses	±50%	1
CO_{2eq}	±5%	1

Table LIV - GHG Uncertainties (Neelis & Blinde, 2010; Olivier et al., 2009; Ramírez et al., 2006)

Herein, the relatively low CO_2 uncertainty margins are due to their being calculated fairly straight-forward through (directly measured) activity-data and process emissions. Those CO_2 emissions relating to land-usage are fairly uncertain, but attribute a relatively small amount to the aggregated CO_2 emissions. The uncertainty margin for the other GHG emissions are much larger due to the fact that these emissions are predominantly calculated based on estimates, models and distribution keys.

Additional uncertainties arise when these national uncertainty margins are adapted to the municipal level. Regionalized data should therefore predominantly be viewed as being indicative.

General Developments 'Intended Policies': National and Municipal Demographics until 2030

The major demographic developments have been supplied via projections as provided by the CBS and the PBL with respect for the Netherlands as a whole (Table LVV), and for the municipalities of Utrecht and De Bilt for the period 2014-2030 (PBL & CBS, 2013b; PBL & CBS, 2013a). As a general rule, households with a higher population density (i.e. 'larger' households) are deemed more energy-efficient when compared to those households with a low density (i.e. 'smaller' households) so that a smaller household will generally require more energy per resident than a larger household.

Netherlands	Population	Growth Rates (%)	Households	Growth Rates (%)	Household Density
2014	16,824,200		7,630,500		2.20
2015	16,870,700	0.28	7,688,500	0.76	2.19
2016	16,920,200	0.29	7,744,200	0.72	2.18
2017	16,973,100	0.31	7,801,700	0.74	2.18
2018	17,030,200	0.34	7,858,100	0.72	2.17
2019	17,086,400	0.33	7,913,300	0.70	2.16
2020	17,141,100	0.32	7,966,600	0.67	2.15
2021	17,193,900	0.31	8,017,300	0.64	2.14
2022	17,245,100	0.30	8,066,100	0.61	2.14
2023	17,294,400	0.29	8,112,200	0.57	2.13
2024	17,342,400	0.28	8,157,000	0.55	2.13
2025	17,389,100	0.27	8,198,400	0.51	2.12
2026	17,434,100	0.26	8,237,800	0.48	2.12
2027	17,477,100	0.25	8,274,300	0.44	2.11
2028	17,518,100	0.23	8,308,700	0.42	2.11
2029	17,557,000	0.22	8,340,200	0.38	2.11
2030	17,593,700	0.21	8,369,000	0.35	2.10

Table LV - Demographical Prognosis for The Netherlands 2014-2030 (PBL & CBS, 2013b; PBL & CBS, 2013a)

With respect to the Netherlands, in absolute terms, the population is expected to continue to grow (+4.6% in total). The annual population growth rates for 2015-2030 are half of those of 1990-2012 (Hekkenberg & Verdonk, 2014) and this the growth-rate is expected to flatten even more. The absolute increase in households amounts to +9.7%. The annual growth rates for the number of households are expected to decrease more significantly; effectively halving the rate of growth between 2015 and 2030. However, their growth rates remain significantly larger than the population growth rates, effectively lowering the average household density (i.e. number of people per household; -4.5% in total). This implies a lowered average household energy-efficiency in terms of a decrease in household density.

Year	**Population**	**Growth Rates (%)**	**Households**	**Growth Rates (%)**	**Household Density**
Utrecht					
2014	324900	-	170200	-	1,91
2015	328600	1,14	172300	1,23	1,91
2016	331900	1,00	173600	0,75	1,91
2017	336300	1,33	175900	1,32	1,91
2018	341100	1,43	178000	1,19	1,92
2019	346300	1,52	180300	1,29	1,92
2020	351400	1,47	182600	1,28	1,92
2021	357500	1,74	185200	1,42	1,93
2022	363600	1,71	188100	1,57	1,93
2023	369600	1,65	190700	1,38	1,94
2024	375600	1,62	193500	1,47	1,94
2025	381300	1,52	196200	1,40	1,94
2026	386700	1,42	198800	1,33	1,95
2027	391600	1,27	201200	1,21	1,95
2028	396300	1,20	203600	1,19	1,95
2029	400600	1,09	205800	1,08	1,95
2030	404600	1,00	207900	1,02	1,95
De Bilt					
2014	41800	-	19000	-	2,20
2015	41600	-0,48	19100	0,53	2,18
2016	41500	-0,24	19200	0,52	2,16
2017	41300	-0,48	19300	0,52	2,14
2018	41100	-0,48	19300	0,00	2,13
2019	41000	-0,24	19400	0,52	2,11
2020	40900	-0,24	19500	0,52	2,10
2021	40800	-0,24	19600	0,51	2,08
2022	40600	-0,49	19600	0,00	2,07
2023	40600	0,00	19600	0,00	2,07
2024	40500	-0,25	19600	0,00	2,07
2025	40400	-0,25	19700	0,51	2,05
2026	40400	0,00	19700	0,00	2,05
2027	40400	0,00	19800	0,51	2,04
2028	40400	0,00	19800	0,00	2,04
2029	40200	-0,50	19800	0,00	2,03
2030	40200	0,00	19800	0,00	2,03

Table LVI - Demographical Prognosis for Utrecht and De Bilt 2014-2030 (PBL & CBS, 2013b; PBL & CBS, 2013a)

With respect to the municipality of Utrecht, the absolute population is expected to rise at a much faster rate than the national average (+24,5% in total) and, though an overall decreasing trend in the associated growth rates is identified, this is of a more erratic character. The same can be said with respect to the absolute growth in households (+22,2% in total) and the associated growth rates. Average household density remains fairly constant (+2,1% in total) implying fairly constant energy-efficiency in terms of a fairly constant household density. The municipality De Bilt has about ten times less inhabitants than the municipality of Utrecht. In contrast to Utrecht and the national prognosis, this absolute population is expected to decrease further (albeit marginally at -3,8% in total) over 2014-2030. The number of households, however, is expected to increase marginally (+4,2% in total); implying a relative lowering in average household density (-7,7% in total) in excess of those as identified in the National prognosis and those relating to the municipality of Utrecht.

General Developments 'Intended Policies': Energy-markets until 2030

Developments in the (inter)national energy markets have a large influence on the projected municipal energy-systems. These developments mostly relate to the prices of the following fossil fuels: oil, coal and natural gas. These prices as presented in the 'Nationale Energieverkenning' are derived out of the International Energy Agency's (IEA) 2013 World Energy Outlook and correspond to developments as set-up in the 'Intended policies' scenario as propounded by the ECN (Michiel Hekkenberg & Verdonk, 2014a). The respective data is presented in *Table LVII*.

Herein, oil is predominantly viewed as an indispensable part of the transport sector and, to a lesser extent, the petrochemical industry. The price of oil is intimately related to the price of diesel, gasoline and LPG and is traded on a worldwide-market (i.e. the price of a barrel of oil does not differ significantly per country). After experiencing a decrease in price due to economic crisis, more recently (i.e. post 2009) the demand for oil has risen again, which is mostly attributed to a larger demand from the upcoming economies (e.g. China). In addition, unstable geo-political situations have suppressed conventional oil production which, in turn, led to an increased influx of unconventional oils (e.g. oil derived from tar sands). Generally, it is expected that the global demand for oil increases (predominantly due to the increasing demand in transport fuels in the aforementioned upcoming economies and the increasing depletion of economically feasible oil prospects), leading to increased prices. The projected oil price experiences a small 'dip' in 2015 only to gradually increase to 143 US dollars a barrel in 2030.

The projected gas-prices are mostly related to developments in the European-Russian gas market, a distinct market which is expected to maintain its price in between the cheaper American gas market and the more expensive Asian market. Herein, the Dutch gas price increased from 2004 on and decreased slightly from 2008 on (partly due to decreased demand as a consequence of the economic recession) and is expected to decrease further until 2016 (partly due to relatively warm winters that are expected). With respect to the more long term developments, the price is expected to rise due to an increasing dependency on imports and a decrease in domestic production. Potential European shale-gas prospects are not expected to have a significant influence on the price. The small 'dip' in price in 2015 is succeeded by a relatively large price increase up to 0.32 euro per cubic metre in 2030.

Similar to oil, coal is traded on international markets and since the Netherlands does not mine for coal, it is imported. For the past years the coal-price has been erratic. However, due to the opening of a large number of new mines, the price is expected to drop over 2015. Hereafter, due to increasing international demands, the price is expected to rise sharply and reach 94 euro per tonne in 2030.

The projected wholesale price of electricity is a direct result of the price-developments in the aforementioned energy-carriers, as well as expected developments relating to the sustainable production of energy in a European energy-market that is aimed at achieving one integrated market. Similarly to the above, the price is expected to drop slightly before rising to 59 euro per MWh in 2030.

	Description	**Unit**	**2013**	**2014**	**2015**	**2020**	**2023**	**2030**
Oil	North Sea Brent	US dollar per barrel	113	112	107	127	131	143
Gas	Wholesale price	Euro per m^3	0.24	0.26	0.24	0.30	0.30	0.32
Coal	Import 'ketelkolen' Nederland	Euro per tonne	81	64	63	89	91	94
Electricity	Wholesale price	Euro per MWh	52	43	43	59	60	59

Table LVII - Projected Oil, Gas, Coal and Electricity Prices (IEA, 2013)

Efficiency of power generation, emission factor of natural gas, carbon intensities of electricity and steam production; including linear interpolations

Year	**Efficiency of gross thermal power generation (%) 'EU Trends'**	**Emission Factor of Natural Gas (Tonne/m^3) 'KlimaatMonitor'**	**Carbon Intensity of Electricity and Steam Prodcution (Tonne CO_{2eq}/kWh) 'KlimaatMonitor'**	**Carbon Intensity of Electricity and Steam Prodcution (Tonne CO_{2eq}/kWh) 'EU Trends'**
2005	**41.5**	**0.001795**	**0.00051**	0.**00035**
2006	42.1	0.001795	0.0005	0.00034
2007	42.7	0.001791	0.0005	0.00033
2008	43.4	0.00178	0.00049	0.00032
2009	44.0	0.00178	0.00048	0.00031
2010	**44.6**	**0.001788**	**0.00046**	0.**0003**
2011	44.3	0.001785	0.00044	0.0003
2012	44.0	0.001785	0.00047	0.0003
2013	43.8	0.001785	0.00048	0.0003
2014	43.5	0.001781	0.000442	0.0003
2015	**43.2**	**0.001779**	**0.000433**	0.**0003**
2016	43.0	0.001778	0.000425	0.000292
2017	42.8	0.001777	0.000417	0.000284
2018	42.7	0.001775	0.000408	0.000276
2019	42.5	0.001774	0.0004	0.000268
2020	**42.3**	**0.001773**	**0.000391**	0.**00026**
2021	42.3	0.001771	0.000383	0.00026
2022	42.3	0.00177	0.000375	0.00026
2023	42.4	0.001769	0.000366	0.00026
2024	42.4	0.001767	0.000358	0.00026
2025	**42.4**	**0.001766**	**0.000349**	0.**00026**
2026	42.7	0.001765	0.000341	0.000254
2027	42.9	0.001763	0.000332	0.000248
2028	43.2	0.001762	0.000324	0.000242
2029	43.4	0.001761	0.000316	0.000236
2030	**43.7**	**0.001759**	**0.000307**	0.**00023**

Table LVIII - Efficiency of power generation, emission factor of natural gas, carbon intensities of electricity and steam production; including linear interpolations

Annual sectoral reduction percentages ‘Intended Policies’ Scenario ECN

Annual Gross End-Use Reduction percentages	**2010-2020**	**2020-2030**
National Total	1.2	0.7
Households	1.8	0.9
Services	1.3	1.3
Transport	0.9	0.5
Industry	0.6	0.4
Agriculture	1.4	0.3

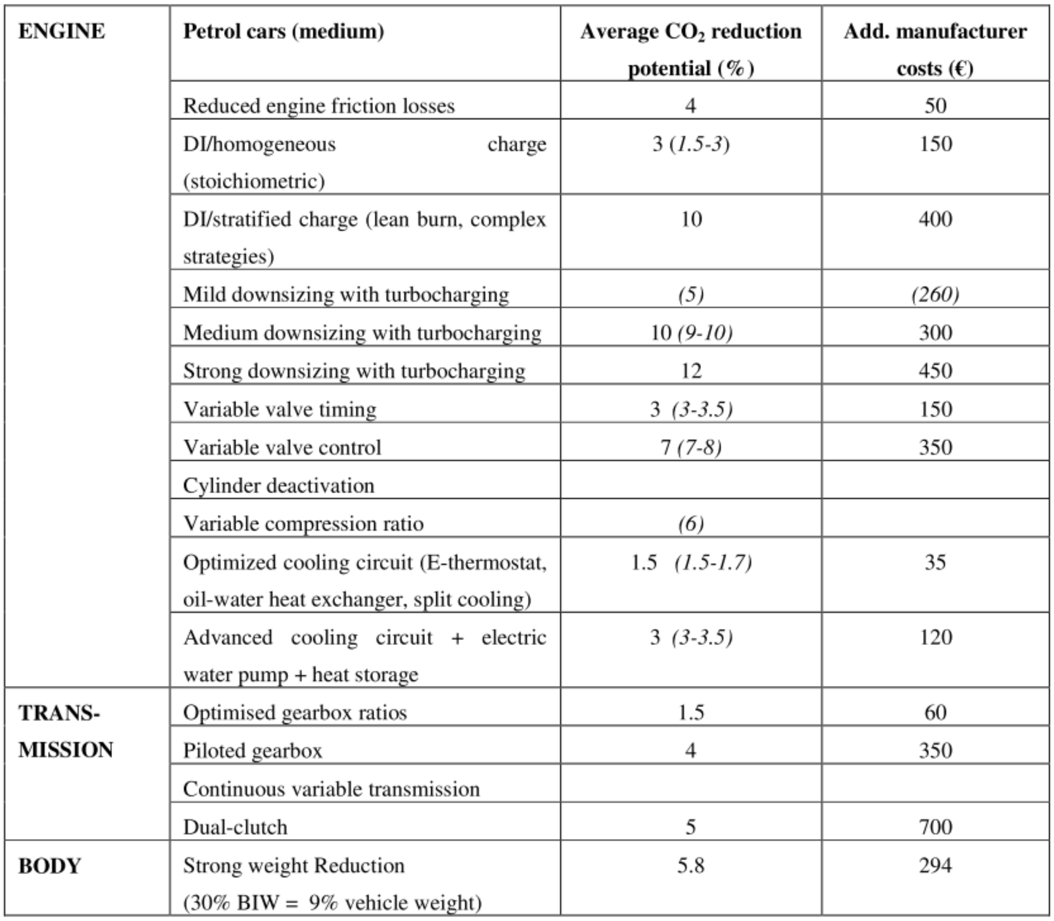
Table LIX - Annual Reduction Percentages per Sector ‘Intended Policies’ (Hekkenberg & Verdonk, 2014b)

Agricultural Abatement Measures

	Measures	**Specific costs (€/tCO$_2$)**	**Mton CO$_{2\text{-eq}}$/ year)**	Cum. Mt CO2-eq year
Soils	Reduce N application through precisison farming	-175	5	5
Soils	Reduced N application through improved spreader maintenance	-173	5	10
Manures	Centralized anaerobic digestion: dairy - West (warm)	-48	0	10
Manures	Centralized anaerobic digestion: dairy - East (temperate)	-19	0	10
Manures	Centralized anaerobic digestion: dairy - West (temperate)	-10	3	13
Manures	Centralized anaerobic digestion: pigs - East (temperate)	-8	0	14
Manures	Centralized anaerobic digestion: pigs - West (temperate)	-7	5	18
Manures	Centralized anaerobic digestion: pigs - West (warm)	-3	1	19
Soils	Reduce N application through fertiliser free zone	-1	1	20
Enteric	Long term management and use of genetic resources (Non-dairy cattle Eastern Europe)	0	5	25
Enteric	Long term management and use of genetic resources (Dairy cattle Eastern Europe)	0	2	27
Enteric	Long term management and use of genetic resources (Dairy cattle Western Europe)	0	3	30
Manures	Reducing the rate of microbial action	0	5	35
Manures	Removal of the gas source	0	8	43
Enteric	Long term management and use of genetic resources (Non-dairy cattle Western Europe)	0	5	48
Soils	Addition of Nitrification inhibitors - Mineral	10	30	78
Soils	Addition of Nitrification inhibitors - Manures	10	29	107
Soils	Reduced grazing on wet areas	18	3	110
Soils	Reduce N application through enhanced distribution geometry	20	5	115
Soils	Reduce N application through allowance for manure/residual N	67	5	120
Manures	On farm anaerobic digestion: dairy - West (warm)	77	0	120
Manures	On farm anaerobic digestion: dairy - East (temperate)	88	0	120
Manures	Centralized anaerobic digestion: dairy - East (warm)	93	0	120
Manures	On farm anaerobic digestion: for pigs - West (warm)	111	4	124
Manures	Centralized anaerobic digestion: pigs - East (warm)	130	0	124
Enteric	Adding oils and oilseeds (Dairy cattle Western Europe)	137	4	128
Manures	On farm anaerobic digestion: dairy - West (temperate)	150	1	129
Enteric	Adding oils and oilseeds (Dairy cattle Eastern Europe)	168	1	130
Manures	On farm anaerobic digestion: pigs - East (warm)	183	0	130
Manures	On farm anaerobic digestion: dairy - East (warm)	186	0	130
Manures	On farm anaerobic digestion: pigs - West (temperate)	193	3	133
Manures	On farm anaerobic digestion: pigs - East (temperate)	214	1	134
Enteric	Adding oils and oilseeds (Non-dairy cattle Eastern Europe)	258	1	135
Enteric	Adding oils and oilseeds (Non-dairy cattle Western Europe)	262	7	143
Enteric	Replacement of roughage with concentrates (Dairy cattle Western Europe)	1,222	3	145
Enteric	Replacement of roughage with concentrates (Dairy cattle Eastern Europe)	1,497	1	146
Enteric	Replacement of roughage with concentrates (Non-dairy cattle Eastern Europe)	2,297	1	147
Enteric	Replacement of roughage with concentrates (Non-dairy cattle Western Europe)	2,338	5	152
Soils	Better livestock nutrient use efficiency - grazing	2,624	3	155
Soils	Better livestock nutrient use efficiency - fertiliser	3,432	6	161

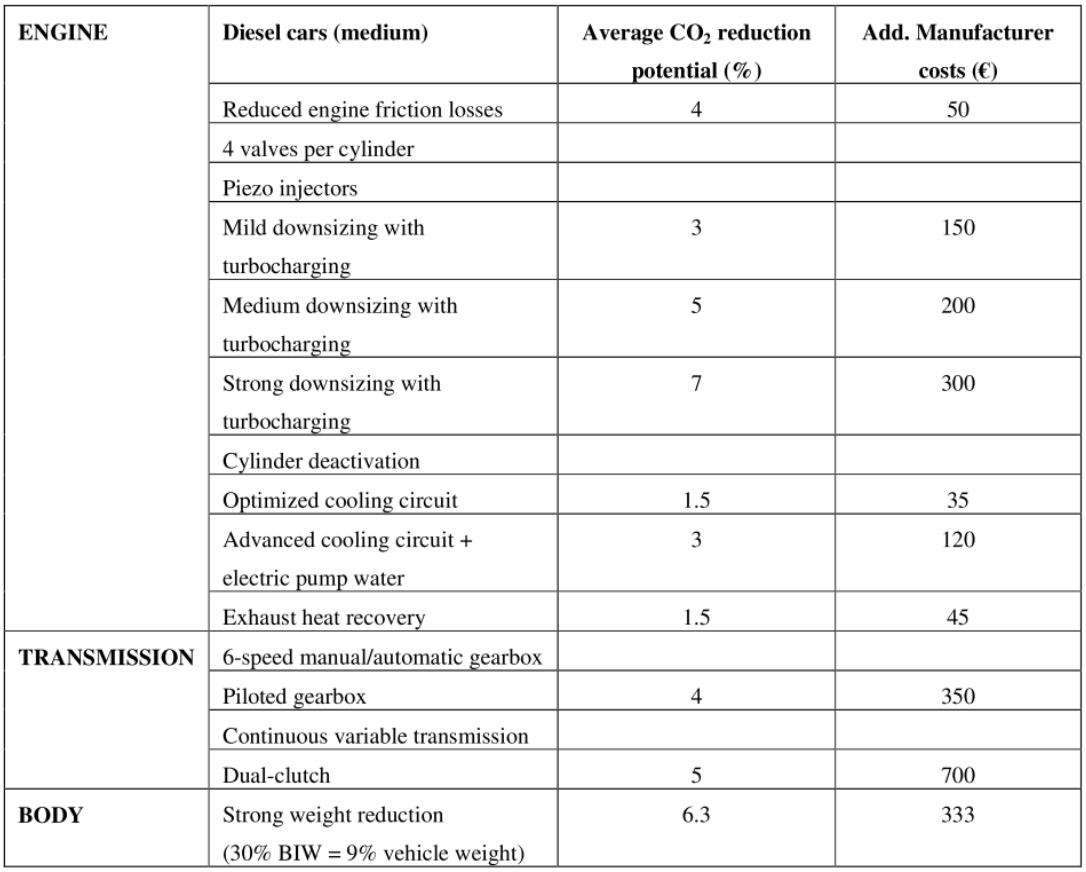
Table LX – Agriculture abatement measures, specific costs, abatement potentials and cumulative abatement potential (Bates et al., 2009)

Potential Powertrain Improvements



ENGINE	**Petrol cars (medium)**	**Average CO_2 reduction potential (%)**	**Add. manufacturer costs (€)**
	Reduced engine friction losses	4	50
	DI/homogeneous charge (stoichiometric)	3 (*1.5-3*)	150
	DI/stratified charge (lean burn, complex strategies)	10	400
	Mild downsizing with turbocharging	*(5)*	*(260)*
	Medium downsizing with turbocharging	10 *(9-10)*	300
	Strong downsizing with turbocharging	12	450
	Variable valve timing	3 *(3-3.5)*	150
	Variable valve control	7 *(7-8)*	350
	Cylinder deactivation		
	Variable compression ratio	*(6)*	
	Optimized cooling circuit (E-thermostat, oil-water heat exchanger, split cooling)	1.5 *(1.5-1.7)*	35
	Advanced cooling circuit + electric water pump + heat storage	3 *(3-3.5)*	120
TRANS-MISSION	Optimised gearbox ratios	1.5	60
	Piloted gearbox	4	350
	Continuous variable transmission		
	Dual-clutch	5	700
BODY	Strong weight Reduction (30% BIW = 9% vehicle weight)	5.8	294

Table LXI - Potential Powertrain Improvements for Average Petrol Cars (Leduc & Blomen, 2009)



ENGINE	**Diesel cars (medium)**	**Average CO_2 reduction potential (%)**	**Add. Manufacturer costs (€)**
	Reduced engine friction losses	4	50
	4 valves per cylinder		
	Piezo injectors		
	Mild downsizing with turbocharging	3	150
	Medium downsizing with turbocharging	5	200
	Strong downsizing with turbocharging	7	300
	Cylinder deactivation		
	Optimized cooling circuit	1.5	35
	Advanced cooling circuit + electric pump water	3	120
	Exhaust heat recovery	1.5	45
TRANSMISSION	6-speed manual/automatic gearbox		
	Piloted gearbox	4	350
	Continuous variable transmission		
	Dual-clutch	5	700
BODY	Strong weight reduction (30% BIW = 9% vehicle weight)	6.3	333

Table LXII - Potential Powertrain Improvements for Average Diesel Cars (Leduc & Blomen, 2009)

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