High renewable energy penetration scenarios and their implications for urban energy and transport systems

Dr. Sven Teske
Corresponding author: sven.teske@uts.edu.au,
University of Technology Sydney (UTS),
235 Jones Street, Ultimo, 2007 Sydney, Australia

Dr. Thomas Pregger, Dr. Sonja Simon, Dr. Tobias Naegler
German Aerospace Center (DLR), Department of Systems Analysis and Technology Assessment, Institute of Engineering Thermodynamics, Pfaffenwaldring 38–40, 70569 Stuttgart, Germany

Abstract

To meet the terms of the 2015 Paris Agreement, the global energy system must be entirely decarbonized by the end of this century. Two scenarios have been developed: a reference case (REF) and an advanced 100% renewable energy scenario (ADV). ADV reflects the trends in global energy systems and will decarbonize the entire energy system by 2050. Those results are compared with the IPCC AR5 450 ppm scenarios, in terms of the 2050 energy demand projections—primary and final energy—and the demands for the transport and building sectors because they are important in urban environments. The results are further discussed with regard to the impact on urban infrastructures and the role of megacities in the global energy consumption pattern. Under the assumption that urbanization rates will remain at the 2015 level until 2050, the annual energy demand for buildings in urban areas is expected to increase by 27 EJ under the reference scenario (REF), from 57 EJ to 84 EJ per year, whereas ADV would lead to an overall reduction to 46 EJ per year by 2050, while the population and GDP continue to grow. Overall, the global energy demand in the transport sector is expected to increase by over 60% by 2050 under REF, whereas the deep mitigation pathway (ADV) reduces the transport energy demand below that of the base year, to 70 EJ per year. This is a significant reduction, even compared with other 450 ppm scenarios, and can be achieved by a drastic shift to electric mobility in response to vehicle efficiency standards, a phasing-out of combustion engines in the transport sector by 2030, and a modal shift in favor of urban public transport. The global energy demand for the building sector in ADV shows a smaller deviation in comparison to other 450 ppm scenarios than that for the transport sector.

Key words: low-carbon scenario; global demand projection; energy efficiency; efficiency standard; global energy scenario; CO_2 reduction; renewable energy; urban infrastructure; comparative AR5 450 ppm scenario

Highlights

• Comparison of deep-decarbonization scenarios reveals large differences in final energy demand projections

• The projected electricity demand for 2050 varies significantly, between 65,000 TWh/yr and 25,000 TWh/yr

• The presented low-carbon ADV scenario combines 100% renewable energy for all sectors with high efficiency

• 100% renewable energy scenarios use high electrification rates for transport and the heating sector

• Estimated CO_2 reduction potential for urban buildings accounts for 35 Gt CO_2 by 2050

1. Background to the mitigation scenarios presented

Article 2 (a) of the 2015 Paris Agreement [1] states that "Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change (…)".The objective of this paper is to compare various deep-mitigation scenarios that use the whole range of energy technologies—including carbon capture and storage (CCS) and nuclear—with a scenario that only uses renewable and energy-efficient technologies. The focus is on projected energy demand for urban buildings and transport, the resulting emissions and the possible impacts on the urban infrastructure. The German Aerospace Center developed the Energy [R]evolution 2015, a global 100% renewable energy scenario [2]**, in close cooperation with Greenpeace and renewable industry associations. The climate mitigation pathway presented here further increases the proportion of renewable energy relative to the Energy [R]evolution scenarios published earlier [3], [4] (which served as the baseline mitigation scenario in Edenhofer et al. [5]) from 80% to 100% by 2050, phasing out energy-related CO_2 entirely by 2050. The assumptions and results of this pathway are compared with the results of other climate mitigation pathways from the AR5 database [21].

Key questions addressed in this paper:
1. What developments are required to meet the energy demand and renewable energy supply for a 100% renewable energy pathway?
2. What are the possible changes in the urban building energy demand?
3. What are the potential impacts of 100% renewable energy pathways on urban infrastructures?

In this paper, we present the methodology, assumptions, and key results of two global scenarios and compare them with those of AR5 scenarios. A subsequent section focuses on urban environments.

2. Methods and assumptions
The scenarios

The scenarios have been developed using the Mesap/PlaNet simulation model. Mesap/Planet contains a detail-rich description of the entire energy system - from useful energy to primary energy demand in the industry, transport, buildings and transformation sectors. Main model parameters are calibrated with the IEA energy balances in the past. The forward projection of those model parameters takes into account various technical, economic and social constraints and interdependencies between sectors and technologies

as well as results and insights from other (modelling) studies. In this way, Mesap/PlaNet allows taking into account broad expert knowledge when developing target-oriented energy scenarios. A more detailed description can be found in Schlenzig [6]. The Reference case (REF) is used as the baseline scenario for comparison with other scenarios and is based on the Current Policies scenarios published by the International Energy Agency (IEA) in World Energy Outlook 2014 [43]. It considers only existing international and national energy and environmental policies. Its assumptions include continuing progress in electricity and gas market reforms, the liberalization of cross-border energy trade, and recent policies designed to combat environmental pollution, without additional climate policies. The IEA's projections to 2040 are extended by extrapolating their key macroeconomic and energy indicators forward to 2050, on the assumption that these parameters will continue to follow the presumed trends between 2035 and 2040 over the following decade. The Advanced Energy [R]evolution (ADV) scenario includes significant efforts to fully exploit the large potential for energy efficiency using mandatory efficiency standards. At the same time, various renewable energy sources are integrated to a large extent for heat and electricity generation and the production of biofuels and hydrogen for the transport sector. The latter will require a strong role for hydrogen and other synthetic fuels in heavy-duty vehicles, shipping, and aviation, complementary to electric battery vehicle concepts for passenger cars, and (limited) biofuels. Furthermore, in the heating- and cooling sector, electricity will play important roles. In ADV, hydrogen plays a minor role in the building sector (2% by 2050) and is used to substitute for natural gas. In the power sector, natural gas will also be replaced by hydrogen. CCS technologies have not been taken into account in the ADV.

Methodology, approach, and main premises

ADV is a target-oriented scenario developed with a primarily "bottom-up" approach (technology-driven). Presumed increases in population, GDP, specific energy demands, and the deployment of renewable energy technologies are important drivers. The supply scenarios were calculated using an accounting framework [6], and the methodology has been also documented in Giles et al. [7]. The model has been applied to develop five global energy scenarios between 2004 and 2015 and over 50 national and regional scenarios.

REF and related specific data - such as efficiencies, load factors, and demand intensities - are based on the Current Policies scenario published by the IEA in World Energy Outlook 2014 and uses the same regional breakdown in 10 world regions (see Appendix Table 14).

The energy demand projections and efficiency potentials for ADV are based on Graus et. al. [8], [9], involving a global annual reduction in energy intensity of 3.55% in ADV, compared with 1.85% in REF. The annually utilized bio energy will be limited to 80 EJ by 2050, to meet Greenpeace sustainability criteria. This amount is based on a global bio energy assessment survey [10]. The expansion of renewable energies defined in ADV are based on recent technology trends [11]*, regional renewable energy potentials, current and future deployment costs [12], [13], and market development projections of the renewable energy industry [14], [15], [16], [24], [17], [18]. In ADV, the annual markets for the dominant renewable power generation technologies will maintain the annual growth rates of the past decade (2004–2015) until 2030 to sustain the expansion rates of the renewable energy RE industry, and will decline to one-digit values between 2030 and 2050 (Table 17, appendix). The annual market for solar photovoltaic systems will increase from 51 GW in 2015 to 280 GW by 2050; that for concentrated solar power plants will increase from around 1 GW to 96 GW, and that for wind power from 64 GW to 250 GW by 2050. The model uses annual growth rates for all supply technologies. The future development pathways for cars and other transportation technologies are based on Schmidt et al. [19] and demand development is calculated from energy intensities based on Oezdemir et al. [44].

Population development: The IEA World Energy Outlook 2014 [43] and the ADV scenario were calculated with an average global population growth of 0.8% per year over the period 2015–2050, increasing from 7 billion to 9.9 billion people by 2050 (Table 13), based on the UN DESA World Population Prospect 2012 (medium fertility variant) [20]. Later UNDESA editions have not been taken into account.

Economic growth is a key driver of energy demand. The average increase in the global gross domestic product (GDP) between 2012 and 2025 is assumed to be 3.4%. The projections based on the regional breakdown until 2050 [43] are shown in Table 14.

Methodology: Calculation of urban building energy demand
IEA [26] uses a breakdown in transport, industry, and other sectors. Other sectors are further subdivided into residential, commercial, and public services buildings, agriculture and forestry, fishing, and 'non-specified'. REF and ADV use the statistical breakdown of the percentages for each region and sector for their projections to 2050, and do not include further sector-specific projections. In this paper, we focus on the transport and building sectors.

Based on IEA [26], the final energy demand for residential, commercial, and public services buildings was calculated from regional populations and urbanization (see Table 1). The results are presented under the term "buildings". This pragmatic methodology leads to inaccuracies, mainly because the different subdivisions have different savings potentials in all 10 regions. However, a more detailed analysis would have exceeded the scope of this study, but further research is required. The World Bank database [41] provides urbanization rates for 2015 (see Table 1), which have been used to estimate the urban building demand. No projections for the future development of urbanization rates by region have been made because they are highly uncertain.

Urbanization rates in 2015 in % (World Bank database)	
Region	2015
OECD North America	82%
OECD Asia Oceania	57%
OECD Europe	75%
Eastern Europe/Eurasia	71%
India	18%
China	57%
Other Asia	17%
Latin America	49%
Middle East	35%
Global average	**54%**

Table 1: Urbanization rates by region (WB 2015)

The use of a constant urbanization rate may lead to an underestimate of the future urban energy demand for building, because a United Nations analysis [42] has suggested that urbanization rates are likely to increase. Therefore, the results are conservative estimates and further research is required.

3. Global results: comparing different mitigation pathways
The detailed results of the 100% renewable energy pathway ADV are compared – as far as possible – with the 450 ppm scenarios published in the IPCC database [21]** , derived with the following models: Ecofys, IMAGE 2.4, Message V4, MiniCam_EMF22, and REMIND 1.5. The transport projections are also compared with IMACLIM V1.1 and POLES EMF27 because these parameters are not available in the previously mentioned models.

Energy demand development:
Under the REF scenario which is based on the IEA Current Policies scenario, the total final energy demand will increase by 65%, from the current 326.9 EJ/yr to 539 EJ/yr in 2050. ADV will lead to a peak demand in 2020, with a total consumption of 355 EJ/yr (7% below that of REF), which will remain at that level for about a decade. With the fast electrification of the transport sector, and the greater

role of public transport, the overall final energy demand will drop below current levels before 2040 and reach 279 EJ/yr by 2050 (15% below the current global demand). Table 2 shows that the ADV and TER 2011 energy demand projections are significantly below those of other AR5 450 ppm scenarios.

Model	Scenario	2050 [EJ/yr]
Mesap/PlaNet	ADV	279
Ecofys	TER 2011	261
IMAGE 2.4	EMF27-450-FullTech	426
Message V4	AMPERE3-450-	543
REMIND 1.5	LIMITS 450	500
Max.	AMPERE3-450P	560
Average	LIMITS-RefPol-450	467
Min.	TER 2011	261

Table 2: Final energy demand projections for 2050

Electricity replaces fuels: In the ADV, the total electricity demand will increase from about 18,860 TWh/yr in 2012 to 40,163 TWh/yr by 2050. Efficiency measures in the industry, residential, and service sectors will avoid the generation of about 16,700 TWh/yr compared with REF (42,622 TWh/yr), but substantially increase the electricity demand in the transport sector. Therefore, the electricity demands in 2050 for REF and ADV are within the same order of magnitude. Around 8,100 TWh/yr will be used in 2050 for electric vehicles and rail transport, around 5,100 TWh/yr for hydrogen, and 3,600 TWh/yr for synthetic liquid fuel generation for the transport sector (excluding bunkers). The electricity share of the total final energy demand will increase from 23% in 2015 to 52% in 2050 in ADV, but to 28% in REF. The ADV projection is consistent with most AR 450 ppm scenarios (Table 3).

Model	Scenario	2050 [TWh/yr]
Mesap/PlaNet	ADV	40,163
Ecofys	TER 2011	35,417
IMAGE 2.4	EMF27-450-FullTech	36,171
Message V4	AMPERE3-450P	42,760
REMIND 1.5	LIMITS 450	58,882
Max.	EMF27-450-NoCCS	65,178
Average	EMF27-450-FullTech	44,537
Min.	AMPERE2-450-Conv-HST	26,208

Table 3: Final electricity demand projections for 2050

Reducing global heat demand in buildings: Under ADV, consumption equivalent to about 76 EJ/yr will be avoided through efficiency gains by 2050 compared with REF. This is attributable to energy-related renovation of the existing stock of residential buildings, the introduction of low energy standards for buildings and electrical appliances, the 'passive climatisation' of new buildings, and highly efficient air-conditioning systems.

Heating supply: The proportion of renewable energy in ADV will increase from 21% to 43% of the global heat demand in 2030 and to 94% in 2050. Up to 2030, biomass will remain the main contributor to the growing market share. After 2030, the continuing growth of solar collectors and the growing proportions of geothermal and environmental heat and heat from renewable hydrogen will further reduce fossil fuel consumption. ADV will result in the complete substitution of the remaining gas consumption (2% in 2050) by hydrogen generated from renewable electricity.

Electricity generation: By 2050, the proportion of global renewable power generation will reach 100% in ADV. Wind, photovoltaic (PV) systems, concentrated solar power (CSP), and geothermal energy will contribute 72% of the total electricity generation, whereas hydro power will supply 7%. By 2025, the proportion of renewable power generated will reach 47%, and 64% by 2030. The installed capacity of renewable energy will reach about 9,500 GW in 2030 and 23,600 GW by 2050. ADV will result in a high proportion of variable-power-generating sources (PV, wind, and ocean), reaching 36% by 2030 and 55% by 2050.

Transport: The REF transport energy demand will increase by around 65% from 90 EJ/yr in 2012 to 148 EJ/yr in 2050. In comparison, ADV will save 62% (92 EJ/yr) in 2050. By 2030, electricity will provide 19% of the transport sector's total energy demand, whereas in 2050, the share will be 52% in ADV. Hydrogen and other synthetic fuels generated with renewable electricity are complementary options that will further increase the proportion of renewable energy used in the transport sector. In 2050, ADV assumes 14 EJ/yr of hydrogen in the transport sector. The transport demand for ADV is by far the lowest of all the AR5 450 ppm scenarios (Table 4). A breakdown of road, rail, aviation, and marine transport demands is not available from the AR5 scenario database, so no further comparison is possible. ADV will reduce the final energy demand for road transport by 49% and increase that for rail by 300%, whereas those for navigation and aviation will remain constant until 2050.

Model	Scenario	2050 [EJ/yr]
Mesap/PlaNet	ADV	57
Ecofys	TER 2011	73
IMAGE 2.4	EMF27-450-FullTech	109
Message V4	AMPERE3-450	170
REMIND 1.5	LIMITS 450	156
Max.	AMPERE3-450P	191
Average	AMPERE2-450-NoCCS-OPT	137
Min.	ADV	57

Table 4: Transport demand projections for 2050

Energy-related CO_2 emissions: Under REF, energy-related CO_2 emissions will increase by 56% between 2012 and 2050. ADV will decarbonize the entire energy system by 2050. By 2030, global CO_2 emissions will be at 1990 levels, and by 2040, a further 60% reduction will be achieved. The total carbon emissions between 2012 and 2050 will total 667 Gt CO_2 in ADV. In comparison, REF will generate 1,400 Gt of CO_2 between 2012 and 2050. ADV will not entail any further greenhouse gases (GHG) emissions and will end in 2050.

Primary energy: The primary energy demand under REF will increase from 534 EJ/yr to 860 EJ/yr in 2050, whereas that under ADV will be 450 EJ/yr in 2050. This value is among the lowest for any scenario analyzed (Table 5). The only remaining fossil fuels are assumed to meet non-energy needs, such as petrochemical and steel products.

Model	Scenario	2050 [EJ/yr]
Mesap/PlaNet	ADV	453
Ecofys	TER 2011	385
IMAGE 2.4	EMF27-450-FullTech	584
Message V4	AMPERE3-450	719
REMIND 1.5	LIMITS 450	670
Max.	AMPERE2-450-LimSW-OPT	767
Average	LIMITS-RefPol-450	629
Min.	TER 2011	385

Table 5: Primary energy demand projections for 2050

Feasibility of 100% renewable energy scenarios
Whether 100% renewable energy scenarios are feasible is currently under discussion in the scientific literature Heard et al. [22]*, Esteban et al.[23] and Brown et al. [25]*. In particular, the feasibility of integrating large quantities of variably generated power (solar and wind), transmission requirements, and ancillary service requirements are debated. Brown et al. [25] address these concerns and provide concrete examples in which renewable power generation already provides almost 100% of regional electricity demands, such as in Paraguay (99%), Norway (97%), and Costa Rica (93%) In 2016, the highest variable renewable electricity shares were in Denmark (37.6%), Ireland (24%) and Portugal (19.7%) [24], [25] where synchronous generators from state-of-the-art wind turbines, as well as solar photovoltaic systems and storage units, were "coupled to the grid with inverters, which have no inherent inertia and low fault current, but can control voltage with both active and reactive power." However, further research is required and systems analyses should be undertaken in the future for all climate-mitigation pathways, not only those with high proportions of renewable energy.

4. Urban climate mitigation pathways
Cities are home to over half the world's population (3.96 billion people), which is expected to increase to 5.1 billion by 2030 [42]. The technical requirements for 100% renewable energy trajectories for urban environments will shape future infrastructural requirements. In the following section, we provide a brief overview of the energy demand projections for the presented trajectories and their expected impacts on infrastructural needs in urban areas. We again compare global sectorial results with those for selected 450 ppm scenarios (see section 3).

Energy demand pathways for the building sector
In most world regions in the base year 2012, the residential energy demand was larger than the commercial and public services demands (except in OECD Asia Oceania).

Fuel and heat use represent the largest share of the total final energy demand in this sector. The share ranges from 51% for OECD North America to 95% for Africa. The residential sector has the largest end-use of fuels and heat, ranging between 44% in OECD Asia Oceania to 91% in Africa. Although residential buildings use a larger share of fuel and heat than commercial buildings, the consumption of electricity is more evenly spread over the subsectors: 48% of electricity is used in residential buildings, 40% in commerce and public services, and the remainder in other economic activities. The use of electricity in the services sector depends strongly on the region, and ranges from 16% in India to 55% in OECD Asia Oceania. The building sector (as defined in section 2) consumes about 40% (including electricity) and 26% (excluding electricity) of the global final energy, a share expected to increase under REF from 130 EJ/yr in 2012 to more than 187 EJ/yr in 2040 (IEA WEO 2014). By 2050, the building sector will consume 203 EJ/yr in REF, 64% more than in the base year. Within this sector, the electricity demand has a relative growth of 130%, whereas the fuel demand is expected to increase most slowly, from 92 EJ/yr in 2012 to 116 EJ/yr in 2050. The energy demand in buildings under REF will grow considerably, with the highest demand in OECD Americas (33 EJ/yr), followed by China (32 EJ/yr) and OECD Europe (29 EJ/yr). Whereas OECD Asia Oceania, Latin America and the Middle East will have the lowest energy demand, of 9–11 EJ/yr.

High-efficiency pathways for urban buildings
The energy efficiency pathways for buildings in ADV will reduce the electricity demand by 33% and fuel use by 46%, compared with REF, in 2050. Compared with 2012, the global fuel use in this sector will decrease from 92 EJ/yr to 62 EJ/yr, whereas electricity use will show a strong increase from 38 EJ/yr to 58 EJ/yr. The final energy demand in the building sector per region will decrease in absolute terms. Although there will be substantial

energy reductions in OECD regions, most developing countries will further increase their energy demands, especially for electricity. Table 6 shows the direct results for REF and ADV, whereas the estimated urban demands for buildings provided in Table 8 are calculated as described in section 2. According to this analysis, and under the assumption that the urbanization rate will remain at the 2015 level until 2050, the annual energy demand for buildings in urban areas will increase by 27 EJ under REF, from 57 EJ/yr to 84 EJ/yr. However, ADV will lead to an overall reduction to 46 EJ/yr by 2050, 11 EJ/yr below the 2012 demand, although the population and GDP will continue to grow. Compared with REF, ADV will reduce the urban building demand by 38 EJ/yr.

Final energy use in "Other sectors" [EJ/yr]									
	2012			**2050 - REF**			**2050 - ADV**		
EJ per year	**Total final energy**	**Fuels/heat**	**Electricity**	**Total final energy**	**Fuels/heat**	**Electricity**	**Total final energy**	**Fuels/heat**	**Electricity**
OECD North America	24	12	12	33	17	16	16	8	8
OECD Asia Oceania	8	4	4	9	5	4	5	3	2
OECD Europe	21	14	7	29	20	9	15	10	5
Eastern Europe/Eurasia	12	11	1	18	16	2	10	9	1
India	10	9	1	17	15	2	13	12	1
China	22	19	3	32	27	5	21	18	3
Other Asia	10	8	1	18	16	3	12	10	2
Latin America	5	4	2	11	8	3	6	4	2
Middle East	5	3	2	11	7	4	6	4	2
Africa	14	14	1	25	24	1	16	15	1
Global	**130**	**97**	**33**	**204**	**154**	**49**	**120**	**93**	**27**

Table 6: Final energy use in "Other sectors" under REF and ADV

Comparison: Global final energy use for buildings [EJ per year] Scenario data: AR5 database (except ADV)			**2050**	**2050**	**2050**
Model	**Scenario**		**Total final energy buildings**	**Buildings: Fuels/heat**	**Buildings: Electricity**
Mesap/PlaNet	ADV		120	93	27
IMAGE 2.4	AMPERE3-450	Maximum	166		
IMAGE 2.4	AMPERE2-450-LowEI-OPT	Average	132		
MESSAGE V4	EMF27-450-EERE	Minimum	89		
IMAGE 2.4	AMPERE3-450P-CE	Maximum			164
MESSAGE V4	AMPERE3-CF450	Average			151
MESSAGE V4	AMPERE2-450-LowEI-HST	Minimum			82
MESSAGE V4	EMF27-550-NoCCS	Maximum		12.2	
IMAGE 2.4	EMF27-FP-FullTech	Average		3.8	
MESSAGE V4	EMF27-Base-LowEI	Minimum		0.2	

Table 7: Comparison of global final energy use for buildings

ADV: Final energy use in residential, commercial, and services buildings; estimated demand for urban buildings [EJ/yr]									
	2012			**2050 - REF**			**2050 - ADV**		
EJ per year	**Residential**	**Commercial & services**	**Estimated urban demand for buildings**	**Residential**	**Commercial & services**	**Estimated urban demand for buildings**	**Residential**	**Commercial & services**	**Estimated urban demand for buildings**
OECD North America	14	8	18	19	11	25	9	6	12
OECD Asia Oceania	3	4	4	4	4	5	2	2	3
OECD Europe	14	5	14	19	7	20	10	4	10
Eastern Europe/Eurasia	8	2	7	13	3	11	7	2	6
India	8	1	2	14	1	3	11	1	2
China	17	2	3	25	3	4	16	2	3
Other Asia	8	1	2	16	1	3	10	1	2
Latin America	4	0	2	8	1	4	4	0	2
Middle East	4	1	1	8	1	3	5	1	2
Africa	13	1	3	23	1	6	14	1	4
Global	**94**	**23**	**57**	**149**	**34**	**84**	**90**	**18**	**46**
Proportion of estimated urban building demand in total demand:		**48%**			**46%**			**43%**	

Table 8: Final energy use in residential, commercial, and service buildings; estimated final energy demand for urban buildings

Table 7 shows that the ADV projection for the final energy demand for buildings is just below the average for the selected 450 ppm scenarios. However, all other 450 ppm scenarios phase-out non-electrical heating supplies, whereas ADV uses substantial amounts of direct heating, mainly solar thermal collectors and district heating systems based on a mix of solar, geothermal, and bio energy. The IPCC AR5 scenario database does not provide further breakdown into energy demand projections for urban residential and commercial buildings, so no further comparison of the REF and ADV results given in Table 8 is possible.

Energy demand pathways for the transport sector
In 2014, the transport sector, including road, rail, aviation, and sea transport, required 27% of the global energy used [26], and 92.7% of the total transport energy demand was provided by oil products, with 2.5% from biofuels and only 1% from electricity [26]**. The breakdown of the final global energy demand under REF by transport mode shows that road transport (mainly passenger transport) will retain the largest share, with only a 3% reduction, from 71% to 68%, in 2050.

The overall energy demand in the transport sector was 90 EJ/yr in 2012 and will increase under REF to 150 EJ/yr in 2050. A drastic global reduction in the transport energy demand under ADV, decreasing below the base year demand to 70 EJ/yr, will be possible under the assumed combination of significant technical efforts—especially in terms of electrification—and a significant reduction in energy through modal shifts (see Table 9), a result of significant improvements in public transport, especially in urbanized areas.

Deep mitigation pathway—changes required in the transport sector with a specific focus on urban areas
The following measures are discussed as suitable to reduce the transport demand in urbanized areas:
- mixed-use developments that form mixed-modal urban hubs that are easily accessible destination points [27];
- improved spatial planning of urban areas and enhanced infrastructure for bicycles and pedestrians [28];
- a significant shift to electric vehicles supplied by renewable electricity such as light rails;
- a gradual reduction in the energy intensities of all modes with technological advances;
- a modal shift from individual cars to public transport systems;

Urban planning and urban transport policies play a key role in this concept, especially with regard to the modal shifts from road to all forms of public transport. Freight transport in urban areas involves small-to-medium-scale delivery vehicles, and their specific energy demand in MJ per tonnes kilometer is assumed to decrease significantly from around 5 MJ/t-km to 2.2 MJ/t-km [44].

Changes in transport modes
Optimized public transport aims to reduce congestion and integration of walkways. [44] There are large differences in the specific energy consumption of transport modes: passenger transport by rail bound vehicles for example will consume 28% less energy than light-duty vehicles in 2050. The vehicle efficiency data that were used for REF and ADV are based on Oezdemir [44] and are presented in the appendix Table 19, Table 20, Table 20, Table 21 and Table 22.

Table 9 shows selected measures, reduction options, and indicators used to reduce the global transport demand in ADV. A normative estimate of the global transport demand in terms of all urban areas is not possible because the required data are unavailable.

Transport Demand: Selected measures, reduction options, indicators		
Measure	**Reduction option**	**Indicator**
Reduction .of transport demand	Reduction in volume of passengers (compared with REF)	passenger-km/capita
	Reduction in the volume of freight transport (compared with REF)	ton-km/unit of GDP
Modal shift	Modal shift from trucks to rail	MJ/ton-km
	Modal shift from cars to public transport and from aviation to rail	MJ/passenger-km
Energy efficiency improvements	Shift to energy-efficient passenger car drive trains (battery electric vehicles, hybrid and fuel cells, hydrogen cars) and trucks (hydrogen fuel cells, electric batteries)	MJ/passenger-km, MJ/ton-km

Table 9: Selection of measures and indicators used to reduce the global transport demand in ADV

Table 10 and Table 11 show the total transport volumes in billion ton per year and passenger kilometer per year for ADV compared with those in selected 450 ppm scenarios. The models use different values for the base year 2010; there are no data for 2012 and only limited data for 2015. To make these results comparable, we calculated the overall changes in percentages.
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	Passenger transport [billion passenger km per year]					
	2010	**2015**	**2050**			
			Min.	**Average**	**Max.**	**Change in %**
IMACLIM V1.1 / AMPERE2-450-FullTech-LST	33,880	35,780	29,540			87%
POLES EMF27 / AMPERE2-450 (all)	25,858	not available		71,724		277%
POLES EMF 27 / EMF27-450-FullTech	46,251	not available			138,801	300%
Mesap/PlaNet / ADV	23,543	23,543	63,546			270%

Table 10: Passenger transport—annual kilometer projections in the transport sector in 2050 under various scenarios

	Freight transport [billion ton km per year]					
	2010	**2015**	**2050**			
			Min.	**Average**	**Max.**	**Change in %**
Ecofys/TER2011	19,341	not available	46,524			241%
POLES EMF27/AMPERE2-450-LimBio-LST	46,268	not available		122,065		264%
POLES AMPERE/AMPERE 3-450	46,130	not available			145,596	316%
Mesap/PlaNet / ADV	29,607	29,607	61,782			209%

Table 11: Freight transport—annual ton kilometer projections in the transport sector in 2050 under various scenarios

Decentralized and centralized generation systems in urbanized areas

The installation of renewable energy systems within urbanized regions and their contribution to supply in those regions are still minor and the technical potential for renewable energy varies significantly under different geographic and meteorological conditions. Decentralized renewable energy systems will play a major role in the implementation of ADV, tapping the technical and economical potential of a whole range of renewable energies. Solar photovoltaic generation and solar thermal systems for water and room heating can be installed on roofs and facades, and over rails, roads, and parking spaces, and devices can be floated on water reservoirs. An analysis of the city of Sydney, a 27 km^2 area with a population density of 8,000 people per km^2, found that "an area equal to 40% of the available roof surfaces could be used to accommodate PV, corresponding to 619 MW$_{peak}$ of potential PV capacity with an expected annual yield of 777 GWh. This equates to 22% of the 3,588 GWh of load in the central-business district (CBD)". The resulting savings in potential CO_2-equivalent emissions would be around 618 kt per year [29]. Another analysis of Apeldoorn, in the Netherlands, a city with a population of 157,700 people and a density of 464 persons per km^2, concluded that the total estimated solar photovoltaic roof-top potential within the city limits could reach 319.9 MW$_{peak}$, with the annual generation of 283.4 GWh/yr, enough to supply the entire city with electricity [30]. Cities located near the coast may benefit from offshore winds and also, in the future, from ocean energy technologies currently under development

[31]. The active involvement of civil society in planning resilient and sustainable cities will be crucial in increasing public acceptance and accelerating public participation. In 2000, Copenhagen was the first capital city to participate in a large offshore wind farm project only 2 km from the city coastline. The offshore wind farm "Middelgrunden" consists of a slightly curved line of 20 turbines, each with a generator size of 2 MW, and was built in a partnership between the municipality and local shareholders [32].

Furthermore, district heating schemes based on geothermal heating technologies to harvest geothermal energy within urban areas can be significant. Zhu et al. [33] concludes that within the city of Shanghai, the existing heat content in the urban aquifer is at least 22 times the annual heating demand of the city.

Infrastructural changes in urban areas

ADV will increase the average global share of variable renewables from 3% in the base year to 24% in 2030 and to over 50% after 2040. In parallel, the electricity share of the transport sector will increase by a factor of 6 by 2025. The overall energy demand of the rail sector will increase by a factor 3, and the electricity demand of road transport will increase from under 0.1% to 53% in 2050. These shares will vary significantly across regions. Regions with high and still increasing urbanization rates will have to substantially alter their infrastructures to implement the technologies presented in ADV. The effect of adding renewable power generation to a conventionally centralized

power system will affect the way in which the system runs. The impact will depend on the share of renewable energy technology [34], [35]. A brief overview of the possible impacts of 100% renewable energy supply systems on urban infrastructures is presented in the next section.

Efficient 100% renewable heating: infrastructural requirements for urban areas

As outlined in ADV, a 100% renewable heating system will involve increased amounts of electric heating systems, such as heat pumps, as well as solar collectors. With high population densities, residential roof space is limited. Therefore, the roof space of commercial buildings might be used for solar installations and the heat transported via district heating pipelines, while geothermal and bio energy heating technologies provide additional capacities. The existing infrastructure of the gas sector can potentially be converted to biogas and/or hydrogen systems. The impact on the urban infrastructure will be threefold:

1. Increased use of electric heating systems will increase the electrical load demand of buildings, which might require the enforcement of distribution grids [36].
2. Expansion and/or implementation of district heating and/or cooling pipelines to distribute renewable heat. Denmark is among the leading countries to expand its district heating network. In 2013, 63% of the heating demand in private Danish houses was provided by district heating systems [37].
3. Conversion of existing gas pipelines to distribute hydrogen will depend on the actual pipeline material used, for example, polyethylene pipelines [38]. Individual technical analyses of the existing pipelines will be required to assess possible future costs.

Increased decentralized power generation: infrastructural requirements for urban areas

A high density of distributed power generators, mainly composed of individual PV systems in a low-kilowatt capacity range, can exert a megawatt impact on single substations. This can result in a reverse load flow when generation exceeds demand within a cluster of the distribution grid. In that case, the surplus electricity must be exported to other regions of the grid. Substations will require specific upgrades to manage such reverse flows, which are further documented in Chojnowski et al. [39].

Electric mobility: requirements for urban infrastructure

• Modal shift: expansion of light rail systems will require the expansion of tracks and related infrastructure.
• Expansion of charging stations for individual electric vehicles in publicly accessible parking areas and privately owned charging stations will significantly change the distribution of load within existing distribution grids. Technical requirements will vary significantly, depending on local conditions [40].

The examples described above only outline a small fraction of the possible future requirements for urban planning. A comprehensive analysis is required, but is not within the scope of this paper.

Estimated carbon emissions from urban buildings

The regional energy-related carbon emissions from urban buildings were calculated based on the projected building energy demands shown in Table 6 and Table 8 and the emission intensities for the building sector under REF and ADV. While the overall annual emissions will increase from 1.6 Gt CO_2 to 1.9 Gt CO_2 by 2050 under REF, a total phase-out of carbon emissions for this sector will be achieved on the ADV trajectory. The total cumulative emissions for urban buildings between 2012 and 2050 will be 69 Gt CO_2 under REF and 33 Gt CO_2 under ADV. The implementation of energy efficiency measures and 100% renewable energy supplies under ADV will avoid the emission of 35 Gt CO_2 between 2012 and 2050.

Table 12 provides an overview of the estimated CO_2 emissions for buildings by region and under the two different trajectories. No comparison with AR5 450 ppm scenarios is possible because the database does not include specific CO_2 emission data for buildings or any further breakdown for urban buildings.

Estimated CO$_2$ emissions and reductions for urban buildings in million tons per year									
CO2 emissions [Gt per year]	2012			2030 Emission Reduction REF - ADV			2050 Emission Reduction REF – ADV (= REF emissions, ADV CO$_2$ emissions are phased-out)		
	Residential	Commercial & services	Total urban buildings	Residential	Commercial & services	Total urban buildings	Residential	Commercial & services	Total urban buildings
OECD North America	383	223	497	150	87	194	399	232	518
OECD Asia Oceania	114	120	133	41	43	48	115	122	135
OECD Europe	464	168	473	245	89	250	493	178	503
Eastern Europe/Eurasia	226	58	201	144	37	129	331	85	295
India	135	10	26	76	6	15	222	16	43
China	425	52	76	302	37	54	560	68	101
Other Asia	125	7	22	86	5	15	266	16	48
Latin America	92	9	49	95	10	51	207	21	112
Middle East	139	22	56	55	9	22	220	34	89
Africa	116	4	30	87	3	22	346	13	88
Total Urban buildings	**2,218**	**673**	**1,565**	**1,282**	**325**	**801**	**3,158**	**786**	**1,931**

Table 12: Estimated energy-related CO$_2$ emissions and reductions for urban buildings

Estimated CO$_2$ emissions and reductions for transport in million tons per year			
CO$_2$ emissions [Gt per year]	2015	2030 Emission Reduction REF - ADV	2050 Emission Reduction REF – ADV (= REF emissions, ADV CO$_2$ emissions are phased-out)
OECD North America	1,998	1,041	1,933
OECD Asia Oceania	439	342	677
OECD Europe	904	451	774
Eastern Europe/Eurasia	304	130	430
India	216	155	771
China	698	404	1,011
Other Asia	430	183	1,313
Latin America	470	257	863
Middle East	422	615	1,709
Africa	285	173	314
Total Transports	6,165	3,752	9,794

Table 13: Estimated energy-related CO$_2$ emissions for transport

5. Discussion of key results and conclusions
Scenario comparison

The ADV scenario results in significantly lower energy demand projections compared to other mitigation pathways. This indicates that a decarbonized energy supply based on 100% renewable energy sources is expected to be even more dependent on ambitious efficiency targets and measures than scenarios with considerable shares of CCS and nuclear technologies. The electrification of heat supply and transportation is a core strategy for both targets achieving high efficiency in energy supply and enabling large-scale integration of renewable energies in all sectors. This has been addressed in most of the scenarios considered, however, with probably quite different pathways for alternative technology options. A detailed comparison of the mitigation pathways is not possible based on the IPCC database as it provides only aggregated scenario results for different sectors without breakdown of various technologies.

The ADV presented and compared with selected AR5 database 450 ppm scenarios has the following characteristics for 2050:

- Final energy demand is among the lowest of all the analyzed scenarios—50% of those of the scenarios with the highest demand (MESSAGE V4, AMERE3-450).
- The projected electricity demand for 2050 under all the analyzed scenarios varies significantly, between 65,000 TWh/yr and 25,000 TWh/yr. This is mainly attributable to the different electrification rates for transport and the heating sector.

- 100% renewable energy scenarios, like ADV presented here, use high electrification rates for transport and the heating sector.
- 100% renewable energy scenarios tend to be dominated by solar PV systems and wind power generation.

The urban perspective

In 2015, urban regions housed around 54% of the global population (Table 1) [41] and played a key role in the implementation of building standards. Although the high population densities and resulting land scarcity are challenging for the installation of renewable energy generators, they are advantageous for the implementation of efficient public and electric transport systems.

The projected energy demands for the building sector in 2050 in all the 450 ppm scenarios analyzed varied significantly less than those in the transport sector. Most will stabilize at the 2020 level, assuming that the increased demand of a growing population and efficiency measures correspond. However, the level of electrification in the heating sector varied significantly.

In the ADV scenario, the energy demand for urban buildings is reduced from 57 EJ/yr in the base year to 46 EJ/yr in 2050. Thus, the energy demand in urban areas is expected to decrease by 20% below the 2012 demand, whereas the global population will continue to increase to 9.9 billion people, an increase of 40% relative to the base year. Renewable power and heating, predominantly solar and wind energy, and a wide range of energy-efficient technologies across all sectors, to reduce both demand and building materials, are expected to be key factors in achieving complete decarbonization. The total CO_2 reduction potential for urban buildings is estimated to be around 35 Gt CO_2. To reduce demand, key interventions for policy makers include energy efficiency standards for electrical appliances, transport technologies, and buildings. These efficiency standards should reflect the assumed energy intensities of low-carbon pathways.

ADV achieved a demand reduction for the transport sector, using modal shifts towards public transport, strict efficiency standards for vehicles and a shift towards electric mobility. To achieve a significant reduction in demand in the transport sector, the average energy intensity for cars should significantly decrease (as e.g. in ADV from 1.40 MJ per passenger kilometer [MJ/p-km] to 0.26 MJ/p-km), which is only possible if fossil-fuel-based combustion engines are phased-out for new cars. In ADV, the annual passenger kilometers are expected to increase by 370% for rail bound systems, but by only 65% for cars. Table 19 and Table 20 in the annex provide a detailed breakdown of the transport energy intensities per mode. No comparison with AR5 450 ppm scenarios is possible because the energy intensities for vehicles are not available.

Significant alteration of urban infrastructure in regard to public transport, electric mobility and accessibility for pedestrians and bicycle use are required in order to achieve both a significant modal shift and a significant share of "new" car technologies. The interconnection of urban infrastructures will require systems thinking and future planning to take new technology developments into account.

To achieve the energy related carbon emission targets of the Paris agreement the implementation of highly energy efficient buildings and transport systems in urbanized areas are mandatory and without alternative in all analyzed mitigation scenarios.

Limitations

To compare mitigation pathways, the AR5 database must be expanded, especially in terms of the energy intensities for specific technologies and detailed sectorial data. The latest actual statistical data for all parameters should be included. The quality of the data is a limiting factor in modeling specific sectorial energy pathways, such as those for urban environments. However, the level of detail in ADV, and also in the analyzed AR5 scenarios, is limited, especially with regard to urban transport. Furthermore, global energy assessments for freight transport, within and between world regions, are not part of the climate-mitigation scenarios and are therefore only qualitative. In addition, model assumptions influencing scenario results such as technology costs, utilization and efficiency are not contained in the database as well.

The feasibility of large proportions of variable renewable energy in power grids is currently under critical discussion in the scientific literature. A systems analysis that includes infrastructural requirements is necessary for future mitigation pathways to allow comprehensive cost–benefit analyses. ADV and all the scenarios of the AR5 database analyzed here only calculate energy balances for an entire year, and not on an hourly basis.

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World region	Countries
OECD Europe	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Israel[1], Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom
OECD North America[2]	Canada, Mexico, United States of America
OECD Asia Oceania	Australia, Japan, Korea (South), New Zealand
Eastern Europe/Eurasia	Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, former Yugoslav Republic of Macedonia, Georgia, Kazakhstan, Kosovo, Kyrgyz Republic, Latvia, Lithuania, Montenegro, Romania, Russia, Serbia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, Cyprus, Gibraltar, Malta[3]
China	People's Republic of China, including Hong Kong
India	India
Other Asia	Afghanistan, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, Chinese Taipei, Cook Islands, East Timor, Fiji, French Polynesia, Indonesia, Kiribati, Democratic People's Republic of Korea, Laos, Macao, Malaysia, Maldives, Mongolia, Myanmar, Nepal, New Caledonia, Pakistan, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Thailand, Tonga, Vanuatu, Vietnam
Latin America[4]	Antigua and Barbuda, Argentina, Aruba, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, British Virgin Islands, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Falkland Islands, French Guyana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Montserrat, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, St. Kitts and Nevis, Saint Lucia, St. Pierre et Miquelon, St. Vincent and Grenadines, Suriname, Trinidad and Tobago, Turks and Caicos Islands, Uruguay, Venezuela
Africa	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of Congo, Cote d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, South Sudan, Sudan, Swaziland, United Republic of Tanzania, Togo, Tunisia, Uganda, Western Sahara, Zambia, Zimbabwe
Middle East	Bahrain, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen

Table 14: World regions used in the scenarios

	2012	2020	2025	2030	2040	2050
World	7080	7717	8083	8425	9039	9551
OECD Europe	564	580	588	594	602	604
OECD North America	477	512	532	551	582	606
OECD Asia Oceania	204	206	207	206	203	199
Eastern Europe/Eurasia	341	341	339	335	326	316
India	1237	1353	1419	1476	1566	1620
China	1384	1440	1457	1461	1444	1393
Other Asia	1086	1193	1254	1308	1395	1449
Latin America	485	526	549	569	601	622
Africa	1084	1312	1468	1634	1999	2393
Middle East	218	253	272	289	322	349

Table 15: Population development projections (in millions; UN World Population Prospects - 2012 Revision, medium variant [42])

	2012–2025	2025–2040	2040–2050	2012–2050
World	3.4%	3.4%	2.2%	3.1%
OECD North America	2.2%	2.3%	1.2%	2.0%
OECD Pacific	1.8%	1.5%	0.5%	1.3%
OECD Europe	1.9%	1.6%	1.0%	1.5%
Eastern Europe/Eurasia	3.5%	2.6%	1.9%	2.7%
India	6.6%	5.5%	3.1%	5.2%
China	5.3%	4.7%	2.7%	4.4%
Other Asia	4.5%	4.5%	3.0%	4.0%
Latin America	3.5%	3.0%	2.2%	2.9%
Middle East	3.9%	3.4%	3.2%	3.5%
Africa	4.8%	4.7%	4.2%	4.6%

Table 16: GDP development projections—average annual growth rates (2012–2040: IEA World Energy Outlook 2014 [43] and 2040–2050: DLR, own extrapolation)

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[1] For statistical reasons, Israel is included in OECD Europe.

[2] IEA WEO 2014 defines the region "OECD Americas" as USA, Canada, Mexico, and Chile, In contrast to the Energy [R]evolution Scenarios, which includes Chile with Latin America to maintain regional integrity.

[3] Cyprus, Gibraltar, and Malta are included in Eurasia for statistical reasons.

[4] Latin America includes Chile, in contrast to IEA WEO 2014.

	REF	ADV	REF	ADV	REF	ADV	REF	ADV	REF	ADV
	Generation [TWh/a]		Installed capacity [GW]		Annual Market Volume [GW/a]		Annual Growth Rate based on Generation in [TWh/a]		Electricity Share [%/a]	
2030	30,639	29689	9,130	13146						
2050	42,622	40163	12,033	25835						
PV 2030	630	5067	494	3725	16	288	5%	19%	13.7%	17.1%
PV 2050	1096	13613	803	9295	15	279	3%	5%	26.8%	33.9%
CSP2030	85	2552	26	635	1	59	11%	39%	5.7%	8.6%
CSP2050	303	14035	74	2555	2	96	7%	9%	22.0%	34.9%
Wind										
on+offshore2030	1962	7737	807	3064	25	216	5%	15%	22.4%	26.1%
on+offshore2050	3202	21673	1217	8040	21	249	3%	6%	40.4%	54.0%
Geothermal										
for power generation										
2030	188	1149	28	171	1	14	6%	21%	3.3%	3.9%
2050	425	4547	62	708	2	27	4%	8%	8.9%	11.3%
bioenergy										
for power generation										
2030	1039	1993	199	405	5	21	4%	8%	6.8%	6.7%
2050	1577	3193	293	742	5	17	2%	3%	8.2%	7.9%
ocean										
2030	10	363	4	131	0	12	15%	31%	0.9%	1.2%
2050	76	2010	28	738	1	30	11%	9%	4.0%	5.0%
hydro										
2030	5207	4621	1544	1402	21	9	2%	1%	16.5%	15.6%
2050	6431	4966	1878	1536	17	7	1%	0%	13.3%	12.4%

Table 17: Renewable energy market developments under REF and ADV

Region	Relative substitution of air traffic with high-speed rail in 2050 under ADV	
	Domestic	Inter-regional
OECD Europe	30%	15%
OECD North America	20%	10%
OECD Asia Oceania	20%	10%
Latin America	30%	10%
Non-OECD Asia	20%	10%
Eastern Europe/Eurasia	10%	10%
China	20%	10%
Middle East	30%	10%
India	20%	10%
Africa	20%	10%

Table 18 Relative substitution of air traffic with high-speed rail in 2050 under ADV

Energy Intensities and potential for passenger transport

MJ/person km	2012	2030	2050
LDV	1.5	0.7	0.3
Passenger Railway	0.4	0.3	0.2
Domestic Aviation	2.5	1.8	1.3

Table 19: Energy Intensities and potential for passenger transport [27]

Energy Intensities and potential for freight transport

MJ/ton-km	2012	2030	2050
Railway	0.12	0.14	0.09
Inland Navigation	0.5	0.4	0.3
HDV	1.6	1.3	0.8
MDV	4.8	4.0	2.7

Table 20 Vehicle technologies for city applications—public transport; technical data for 2015–2020 [44]

Energy Intensities and potential for Light-Duty-Vehicles - REFERENCE

MJ/person km	2012	2030	2050
OECD Europe	1.4	1.0	0.9
OECD America	2.4	1.6	1.0
OECD Asia Oceania	1.3	0.9	0.6
Africa	1.6	1.1	0.9
China	1.4	0.9	0.6
India	1.5	1.0	0.7
Latin America	1.5	1.1	1.0
Other Developing Asia	1.5	1.0	0.8
Eastern Europe/Transition Economies	1.5	1.2	0.9
Middle East	1.6	1.0	0.9
Weighted Average	**1.6**	**1.1**	**0.8**

Table 21: Energy Intensities and potential for passenger transport [44]

Energy Intensities and potential for Light-Duty-Vehicles - ADV

MJ/person km	2012	2030	2050
OECD Europe	1.4	0.6	0.2
OECD America	2.4	0.9	0.2
OECD Asia Oceania	1.3	0.6	0.3
Africa	1.6	1.0	0.7
China	1.3	0.6	0.2
India	1.5	0.7	0.2
Latin America	1.5	0.6	0.3
Other Developing Asia	1.5	0.8	0.3
Eastern Europe/Transition Economies	1.5	0.6	0.3
Middle East	1.6	0.6	0.3
Weighted Average	**1.6**	**0.7**	**0.3**

Table 22: Energy Intensities and potential for passenger transport [44]

Final energy demand in PJ/yr	REFERENCE:		
	2012	2030	2050
Total (incl. non-energy use)	360,650	485,226	587,701
Total energy use 1)	326,859	441,590	538,502
Transport	90,119	122,511	148,418
- Oil products	82,794	109,825	128,112
- Natural gas	3,765	5,427	9,020
- Biofuels	2,486	5,352	7,982
- Synfuels	0	0	0
- Electricity	1,074	1,907	3,304
RES electricity	225	480	865
- Hydrogen	0	0	0
RES share Transport	3%	5%	6%
Industry	106,313	151,290	186,496
- Electricity	28,747	46,689	62,870
RES electricity	6,034	11,746	16,449
- Public district heat	5,446	6,473	6,446
RES district heat	113	394	508
- Hard coal & lignite	25,402	34,396	36,033
- Oil products	12,939	14,824	14,585
- Gas	26,305	36,828	48,889
- Solar	13	141	470
- Biomass	7,441	11,909	17,158
- Geothermal	20	29	45
- Hydrogen	0	0	0
RES share Industry	13%	16%	19%
Other Sectors	130,428	167,789	203,589
- Electricity	38,088	61,705	87,266
RES electricity	7,994	15,524	22,832
- Public district heat	6,555	7,229	8,285
RES district heat	136	440	654
- Hard coal & lignite	5,718	6,076	5,903
- Oil products	17,894	18,940	19,849
- Gas	24,960	34,091	43,036
- Solar	790	1,964	3,359
- Biomass	36,126	37,177	34,701
- Geothermal	297	605	1,189
- Hydrogen	0	0	0
RES share Other Sectors	35%	33%	31%
Total RES	61,675	85,762	106,213
RES share	19%	19%	20%

Table 23: Final energy demand 2012, 2030, 2050; REFERENCE case

Final energy demand in PJ/yr	ADV:		
	2012	2030	2050
Total (incl. non-energy use)	360,650	379,271	313,575
Total energy use 1)	326,859	342,204	278,953
Transport	90,119	85,457	56,534
- Oil products	82,794	59,782	0
- Natural gas	3,765	3,161	0
- Biofuels	2,486	6,247	7,866
- Synfuels	0	467	5,387
- Electricity	1,074	12,027	29,242
RES electricity	225	7,686	29,242
- Hydrogen	0	3,773	14,039
RES share Transport	3%	19%	100%
Industry	106,313	121,143	98,630
- Electricity	28,747	43,008	52,409
RES electricity	6,034	27,486	52,408
- Public district heat	5,446	6,852	6,787
RES district heat	113	2,925	6,787
- Hard coal & lignite	25,402	19,241	0
- Oil products	12,939	5,425	0
- Gas	26,305	27,636	0
- Solar	13	4,440	11,791
- Biomass	7,441	11,315	11,302
- Geothermal	20	2,842	8,004
- Hydrogen	0	382	8,338
RES share Industry	13%	41%	100%
Other Sectors	130,428	135,605	123,788
- Electricity	38,088	51,885	63,763
RES electricity	7,994	33,158	63,762
- Public district heat	6,555	9,188	11,919
RES district heat	136	3,922	11,919
- Hard coal & lignite	5,718	1,437	0
- Oil products	17,894	8,833	0
- Gas	24,960	22,016	0
- Solar	790	7,386	16,833
- Biomass	36,126	31,508	19,322
- Geothermal	297	3,019	9,606
- Hydrogen	0	334	2,346
RES share Other Sectors	35%	58%	100%
Total RES	61,675	145,102	278,949
RES share	19%	42%	100%

Table 24: Final energy demand 2012, 2030, 2050; ADV case