



Contract N°: IEE/11/845/SI2.616378

Bringing Europe and Third countries closer together through renewable Energies

BETTER

D5.2.1: Renewable energy targets, potentials and energy demand scenarios of Turkey

Work Package 5.1 Leader Organization: **TUWIEN** Project Coordinator: **CIEMAT**



October 2013





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Author: André Ortner Work Package 5.1 Leader Organization: TUWIEN Project Coordinator: CIEMAT

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PREFACE

BETTER intends to address RES cooperation between the EU and third countries. The RES Directive allows Member States to cooperate with third countries to achieve their 2020 RES targets in a more cost efficient way. The core objective of BETTER is to assess, through case studies, stakeholders involvement and integrated analysis, to what extent this cooperation *can help Europe achieve its RES targets in 2020 and beyond, trigger the deployment of RES electricity projects in third countries and create win-win circumstances for all involved parties.*

The case studies focusing on **North Africa, the Western Balkans and Turkey** will investigate the technical, socio-economic and environmental aspects of RES cooperation. Additionally, an integrated assessment will be undertaken from the "EU plus third countries" perspective, including a quantitative cost-benefit evaluation of feasible policy approaches as well as strategic power system analyses. Impacts on the achievement of EU climate targets, energy security, and macro-economic aspects will be also analysed.

The strong involvement of all relevant stakeholders will enable a more thorough understanding of the variables at play, an identification and prioritisation of necessary policy prerequisites. The dissemination strategy lays a special emphasis on reaching European-wide actors and stakeholders, well, beyond the target area region.

N°	Participant name	Short Name	Country code
CO1	Centro de Investigaciones Energéticas, Tecnológicas y Medioambientales	CIEMAT	ES
CB2	German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V.)	DLR	DE
CB3	Energy Research Centre of the Netherlands	ECN	NL
CB4	JOANNEUM RESEARCH Forschungsgesellschaft mbH	JR	AT
CB5	National Technical University of Athens	NTUA	GR
CB6	Observatoire Mediterranéen de l'Energie	OME	FR
CB7	Potsdam Institute for Climate Impact Research	PIK	DE
CB8	Vienna University of Technology	TUWIEN	AT
CB9	United Nations Development Program	UNDP	HR

PROJECT PARTNERS



Contents

1	INTRODUCTION	6
2	RENEWABLE ENERGY TARGETS	7
3	RENEWABLE ENERGY POTENTIALS AND RELATED COSTS	8
	3.1 RES potentials	8
	3.1.1 Hydro	9
	3.1.2 Solar	11
	3.1.3 Wind	12
	3.1.4 Biomass	14
	3.1.5 Geothermal	15
	3.1.6 Tide and Wave	16
	3.2 RES technology costs	16
4	ENERGY DEMAND SCENARIOS	23
5	REFERENCES	31
6	ANNEX 1 – REFERENCES USED IN THE ASSESSMENT OF THE RES POTENTIAL	33

Figures and Tables

Figure 1: Hypothetical RES share targets of Turkey under several assumptions of future binding RES	
targets of the EU	.8
Figure 2: Geographical distribution of hydro power plants in Turkey (PLATTS 2013)	11
Figure 3: Solar irradiation distribution of Turkey (Average of the years 2005 to 2011)	12
Figure 4: Average full-load hours of wind electricity generation in Turkey (years 2005 to 2011)	13
Figure 5: Long-run marginal generation costs (for the year 2010) for various RES-E options in EU	
countries	22
Figure 6: Long-run marginal generation costs (for the year 2010) for various RES-H options in EU	
countries	22
Figure 7: Long-run marginal generation costs (for the year 2010) for various RES-T options in EU countrie	es
, 	23
Figure 8: Historic and assumed GDP of Turkey up to 2050 according to two scenarios	25
Figure 9: Historic and assumed population of Turkey according to two scenarios	26
Figure 10: Historic and assumed gross energy demand of Turkey up to 2050 according to several	
scenarios	27
Figure 11: Historic and assumed gross electricity consumption per capita according to several scenarios	
compared to the PRIMES 2011 reference scenario of the EU27	28
Figure 12: Historic and assumed gross electricity consumption of Turkey up to 2050 according to several	
scenarios	29
Figure 13: Assumed energy efficiency trends up to 2050 based on the difference of the PRIMES 2011	
reference scenario and the PRIMES 2011 energy efficiency scenario of the EU27	30
Figure 14: Reference energy demand scenario of Turkey by sector	31
Figure 15: Energy Efficiency Demand Scenario of Turkey by sector	31

1 Introduction

This report is part of the Turkey case study within the BETTER analysis framework. The goal of WP 5 is to assess the potential of the 4th cooperation mechanism in helping Europe to achieve its RES-E targets and to trigger the faster implementation of RES electricity projects in Turkey by 2020 and beyond. This report D5.2.1 provides a basis for the detailed analysis of prospects and opportunities for the implementation of the cooperation mechanism with Turkey in WP 5.2., 5.3., 5.4 and 5.5 in providing an overview about official, as well as hypothetical short- and long-run RES targets of Turkey (based on the calculation method of the European Union), a comprehensive overview of RES potentials and costs according to the literature and own assessments and the development of future energy- and electricity demand scenarios up to 2050.

2 Renewable energy targets

The *short-term* RES-E targets of Turkey are defined in the National Strategic Energy Plan of Turkey (MENR 2010) and cover the period up to 2023. The detailed targets for each RES technology are summarized in Table 1. More details about the current RES legislation of Turkey can be found in (Ortner et.al. 2013).

Table 1 Renewable targets defined in the Strategic Plan covering the period 2010-2014

Resource type	Targets defined in Supply Security Strategy Paper
Wind energy	From 802,8 MW in 2009, increase to 10, 000 MW by 2015, and
	20,000 MW in 2023
Hydro power	Construction of 5,000 MW plants should be completed in 2023
Geothermal	Installed capacity of 77,2 MW in 2009 should be increased up to
	300 MW by 2015
Solar	600 MW until the 31 December 2013, while the maximum
	capacity of a single installation is limited to 50 MW
Biomass	2,000 MW in 2023

Additionally, an overall RES-E target has been declared in the "Electric Energy Market and supply Security Strategy Paper" (MENR 2009b). This strategy document states amongst others a roadmap for increasing the share of renewable energy in electricity generation. The target is to increase the share of renewable resources in electricity generation by 2023 to at least 30 percent. Besides the definition of those targets no other official commitments regarding future RES targets have been declared so far, especially no overall RES target has been defined. However, in case Turkey will access the European energy treaty, a similar approach as for the RES target calculation of EU member states has to be applied to calculate Turkey's RES targets.

The calculation method to share an overall RES target among member states is based on a flat rate increase plus GDP adjustment and is defined in (EC 2008). For the year 2020, the overall RES share of the EU27 of 20% can be used to derive the hypothetical share of Turkey by making use of the same methodology. For the long-term period up to 2050 there is still no legally binding RES target defined on EU level and thus only assumptions can be taken as a basis to calculate corresponding RES shares for Turkey. In this study we base our assumptions on the scenarios developed in Energy Roadmap of the EU (EC 2011).

Figure 1 shows the hypothetical RES share targets Turkey would have to fulfill according to the calculation method of (EC 2008) and the assumption of different future binding RES shares of the EU. The assumptions regarding the future development of the economy and

the energy demand of Turkey are based on the *High-eff scenario* developed in section 4 of this report. As the RES share in 2020 is already fixed and accordingly the several scenarios do not differ the corresponding RES share of Turkey has been calculated to 21.9%. In 2030 the requested RES share varies with regard to the different EU RES targets between 35.2 and 37.5%. Up to 2050 the average value is around 50% and varies in between 49.8 and 62.7%.



Figure 1: Hypothetical RES share targets of Turkey under several assumptions of future binding RES targets of the EU

3 Renewable energy potentials and related costs

3.1 RES potentials

In the course of this task more than 60 relevant scientific papers and national RES potential studies have been reviewed to get a comprehensive overview on the resource availability of RES within Turkey. During the reviewing process it turned out that in this area of literature there is an unusual high occurrence of mutual referencing and that a considerable number of papers make reference to the same source of origin. Consequently, the papers to be considered within the overview have been reduced via backtracking to 40, but it should be noted that due to data conversions, roundings and suchlike the occurrence of double-referencing could not be guaranteed. The presented results should be interpreted against this background information. In addition to the literature research we also present results from an own assessment of solar and wind potential of Turkey, which is based on the analysis of a comprehensive set of meteorological data. Finally, in Annex 1 a summary

of the RES potential data templates we are going to use within the Turkey case study is given. Annex 2 contains the full list of references that were considered within the assessment of Turkey's RES potential. In the following subchapters the resource availability of the several RES technologies are discussed separately.

3.1.1 Hydro

Due to its favorable topography and the fact that large rivers like the Firat River (Euphrates) and the Dicle River (Tirgis) has its origin in Turkey, the countries water resources are ranked within the first quartile within European countries. However, in terms available water per capita, Turkey cannot be classified as water rich country. (Akpinar 2013) estimates that Turkey dispose of a net water potential of about 112 billion m3. Based on the population forecasts of (TURKSTAT 2013) this amount would correspond to 1198 and 1013 m3 per capita in 2050, respectively. In contrast, water rich countries have an available net water potential of at least 5000 m3 per capita. In the view of the above and also considering problems arising from the unbalanced regional distribution of resources and precipitation, as well as the lack of an integrated water management on part of the government, existing estimations on the available amount of water resources for generating electricity has to be interpreted carefully. In 2009 an average annual electricity generation of 48 TWh has been generated by 172 power plants, which is about according to (DSI 2009) approximately 35% of the economically viable hydro power potential in Turkey (Table 2).

Status of HEPP power plants	atus of HEPP power plants Number of plants		Average annual generation	
	[1]	[MW]	[GWh/yr]	
In operation	172	13,700	48,000	
Under construction	148	8,600	20,000	
In program	1,418	22,700	72,000	
Total economic potential	1,738	45,000	140,000	

Table 2: Current deployment of the economic hydro power potential in Turkey (status of 2009)

An additional capacity of 8.6 GW is currently under construction and 22.7 GW are planned to be built in the future in order to exploit the declared economic potential totally. The existing power plants are mainly large-scale units (cf. Table 3), whereas the majority of electricity were generated in plants with dams and a minor share of a view percent in run-off-river and canal plants. At the moment, there are no pump storage units in operation. A number of feasibility studies are currently being processed by the national transmission grid operator TEIAS. It is assumed that approximately 5-10 % of the total potential can be provided by small-scale power plants.

Classification	Number of plants	Total installed capacity	Average annual energy	Contribution to total annual energy
[MW]	[1]	[MW]	[GWh/yr]	[%]
Large hydro (> 50)	46	13047.14	46165.0	89.06
Medium hydro (10-50)	51	1207.97	4450.3	8.59
Small hydro (2-10)	96	298.51	1222.9	2.36
Mini hydro (0.5-2)	71	291.09	1194.6	2.30
Micro hydro (0.01-0.5)	25	7.42	28.3	0.06
Pico hydro (<0.01)	-	-	-	-
Total	193	14553.62	51837.5	100

Fable 3: Distribution of	existing hydropower	plants according to their	installed capacity (status of 2011)
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The technical potential of hydro power in Turkey varies according to the reviewed studies in between 112 and 216 TWh per year. The following graphs show the technical potential in terms of generation and installed capacity over the number of studies.



In Figure 2 the current geographical distribution of hydro power plants in Turkey is shown. The majority of resources are located in the Eastern part of the country, whereas the load centers are in the west and southern part of Turkey. The water resources can be divided into 25 hydraulic basins, which differ significantly in terms of their respective water potential. The Euphrates-Tigris basin alone makes up about 28% of the total water potential of all regions (Akpınar 2013). Within this region a considerable amount of projects are developed as part of the Southeastern Anatolia Project (GAP). In the past the utilization of this area was subject of a conflict between Turkey and its neighbor countries Syria and Iraq. In the meantime bilaterally agreed regulation on minimal inflow rates have calmed down this dispute.



Figure 2: Geographical distribution of hydro power plants in Turkey (PLATTS 2013).

3.1.2 Solar

Estimations of the technical potential of solar power vary according to a number of references in between 380 and 6,105 TWh per year. It should be mentioned that the upper level of the potential is published by a considerable amount of studies, whereas backtracking has led to one paper of (Kaya 2006) that do not contain this figure anywhere in the text. In contrast, this paper states a total solar potential of 35 mtoe, which corresponds to 407,050 GWh per year. This number has also been announced by the Turkish ministry of energy and is marked in red in the figure below.



Figure 3 shows the results from an GIS assessment of the solar irradiation distribution of Turkey that has been performed within this case study. The values are based on (HelioClim 2013) data and are derived from averaging over quarter-hourly radiation data from the years 2005 to 2011. Within this graph we have excluded protected areas and surface gradients over 2.1%. The radiation data is calculation for an inclined plane of 30°, which are

facing south. Within the modeling work in WP5 this data will be used to derive the technical solar potential.



Figure 3: Solar irradiation distribution of Turkey (Average of the years 2005 to 2011)

3.1.3 Wind

According to the literature the technical wind power potential in Turkey varies in between 110 and 290 TWh per year. In terms of installed capacity this translates into a value of 20 GW and 114 GW, respectively. As three sides of Turkey are surrounded by seas with a total coast line of approximately 8337 km, there is also a considerable off-shore wind potential. The off-shore potential is still under evaluation, however the papers supposing a total technical potential of 290 TWh indicate that there might be an offshore potential in the range of 180 TWh.



It has to be noted that the evaluation of a technical potential for wind power is always closely related to estimations regarding available areas and technological parameters like turbine height, rotor diameter and the power transfer function of the turbines installed in the future. Figure 4 shows the results of a GIS assessment of the technical potential of wind energy within Turkey.



Figure 4: Average full-load hours of wind electricity generation in Turkey (years 2005 to 2011)

The data is based on (COSMO-EU 2013) and covers the period from 2005 to 2011. The estimation is based on a selected power curve of a 3MW wind power turbine, a power density of 8.3 MW/km2 and a number of land restrictions. Full-load hours below 1200 are not considered. From this assessment we conclude that there is technical wind power potential of 466 TWh and 275 GW, respectively. This data and the corresponding assumptions on the technical potential utilize all suitable areas within Turkey and do not consider other technical limitations (e.g. grid restrictions) and therefore have to be seen against the background of an optimistic long-term assumption.

3.1.4 Biomass

Within the assessment of the total available potential the various biomass feedstock are subdivided into six categories:

- **Forestry products**: This category covers all forms of wood (e.g. wood fuel, complementary fellings) directly harvested from forests and used for energy purposes.
- **Forestry residues** including the following subcategories: Residues and bark from fellings, sawmill and industrial by-products, and waste wood.
- Agricultural products, often classified as energy crops as cultivated on arable land.
- **Agricultural residues**: Similar to forestry, also in agricultural production a broad set of residues occur for the various crops as cultivated and harvested.
- **Biowaste**: For this assessment only municipal waste is taken into consideration, whereby besides recovery two different disposal streams applied i.e. incineration and land filling.
- Other biogas feedstock: Additionally to land filling and anaerobic digestion of e.g. agricultural residues the following other biogas feedstock are taken into consideration: farm slurries and sewage gas.

Based on this concise categorization, for each sub-category a separate assessment of the available potential has to be undertaken in order to derive the total available biomass energy. It has to be noted that this potential is related to the energy content of the available biomass resource and do not mean the final energy (heat and electricity) that can be extracted from the resource via combustion of the resources within several technologies. The figure below shows the estimations of the available biomass energy potential from the literature. The values vary within the range of 120,952 to 581,500 GWh per year. It should be noted that this potentials do not always contain the same feedstock, are not based on the same estimations regarding energy content, available areas and do not refer to the same year of evaluation. The big variation within the values should be seen in front of this background.



In order to get a more detailed view on the biomass primary potential we have further carried out a bottom-up analysis focusing on the several feedstock categories. Table 4 gives an overview on the aggregated values of the available potential according to several biomass categories. The total value resulting from this bottom-up assessment is marked red in the upper graph.

Category	Available potential
	GWh/yr
Crop residues	63,334
Fruit residues	20,851
Animal waste	27,321
Solid biomass (woodfuel)	50,000
Liquid biofuels	41,906
TOTAL POTENTIAL	203,412

Table 4: Available biomass energy potential of several biomass categories

3.1.5 Geothermal

Due to the fact that Turkey is being crossed by the mountain chain of the Alpide belt, which is an area of intense tectonic activity, it has besides China, Japan, Island and the USA one of world's largest geothermal potentials. The majority of areas with a considerable potential (77.9%) are located within the Aegean region. In general, the hottest sources with a temperature above 100°C can be found in the West of Turkey, whereas also in Middle- and East-Anatolia some sources are situated, however with a lower temperature. Estimations regarding the technical potential. According the several studies the electrical generation potential varies in the range of 1,500 and 4,700 MW and the majority of estimations regarding the potential of direct usage of heat indicate an potential of 31,500 MW (this is also the official number of the Turkish Ministry of Energy and Natural Resources).



3.1.6 Tide and Wave

According to several studies that make reference to the Ministry of Energy and Natural Resources the technical potential of tide and wave power generation is around 18,000 GWh per year.

3.2 RES technology costs

Economic conditions of the various RES technologies are based on both economic and technical specifications, varying across the EU countries.¹ In order to illustrate the economic figures for each technology **Error! Reference source not found.** represents the conomic parameters and accompanying technical specifications for RES technologies in the electricity sector, whilst **Error! Reference source not found.** and **Error! Reference urce not found.** offer the corresponding depiction for RES technologies for heating and cooling and biofuel refineries as relevant for the transport sector. Note that all expressed data aim to reflect the current situation - more precisely, they refer to the year 2010 and are expressed in real terms (i.e. \in_{2010}).

The *Green-X* database and the corresponding model use a quite detailed level of specifying costs and potentials. The analysis is not based on average costs per technology. For each technology, a detailed cost-curve is specified for each year, based on so-called cost-bands. These cost-bands summarize a range of production sites that can be described

¹ Note that in the model *Green-X* the calculation of generation costs for the various generation options is done by a rather complex mechanism, internalized within the overall set of modelling procedures. Thereby, band-specific data (e.g. investment costs, efficiencies, full load-hours, etc.) is linked to general model parameters as interest rate and depreciation time.

by similar cost factors. For each technology a minimum of 6 to 10 cost bands are specified by country. For biomass, at least 50 cost bands are specified for each year in each country.

In the following the current investment cost for RES technologies are described alongside the data provided in Table 5, Table 6 and Table 7, whereby a focus may be put on the description of some key technology options. Since the original development of the *Green-X* database in the year 2004, several updates and adjustments have become necessary due to cost dynamics of RES technologies. In many cases, there was a trend for an increase of investment costs in the years up to 2008, followed by a stagnation or decrease in subsequent years.

Firstly, explanatory notes are provided on the technology-specific investment costs as depicted in Table 6:

- The current costs of biogas plants range from 1445 €/kW_{el} to 5085 €/kW_{el} with landfill gas plants offering the most cost efficient option (1445 €/kW_{el} 2255 €/kW_{el}) and agricultural biogas plants (2890 €/kW_{el} 5085 €/kW_{el}) being the highest cost option within this category;
- The costs of medium- to large-scale biomass plants only changed slightly and currently lie in the range of 2540 €/kW_{el} to 3550 €/kW_{el}. Biomass CHP plants typically show a broader range (2950 €/kW_{el} 4885 €/kW_{el}) as plant sizes are typically lower compared to pure power generation. Among all bioelectricity options waste incineration plants have the highest investment costs ranging from 5150 €/kW_{el} to 7695 €/kW_{el} whereby CHP options show about 5% higher investment cost but offer additional revenues from selling (large amounts of) heat;
- The current investment costs of geothermal power plants are in the range of 2335 €/kW_{el} to 7350 €/kW_{el}., whereby the lower boundary refers to large-scale deep geothermal units as applicable e.g. in Italy, while the upper range comprises enhanced geothermal systems;
- Looking at the investment costs of hydropower as electricity generation option it has to be distinguished between large-scale and small-scale hydropower plants. Within these two categories, the costs depend besides the scale of the units also on site-specific conditions and additional requirements to meet e.g. national / local environmental standards etc. This leads to a comparatively broad cost range from 870 €/kW_{el} to 6265 €/kW_{el} for new large-scale hydropower plants. Corresponding figures for small-scale units vary from 980 €/kW_{el} to 6590 €/kW_{el};

- In 2010 typical PV system costs were in the range 2870 €/kW_{el} to 3480 €/kW_{el}. These cost levels were reached after strong cost declines in the years 2008 and 2009. This reduction in investment cost marks an important departure from the trend of the years 2005 to 2007, during which costs remained flat, as rapidly expanding global PV markets and a shortage of silicon feedstock put upward pressure on both module prices and non-module costs (see e.g. Wiser et al 2009). Before this period of stagnation PV systems had experienced a continuous decline in cost since the start of commercial manufacture in the mid 1970's following a typical learning curve. The new dynamic began to shift in 2008, as expansions on the supply-side coupled with the financial crisis led to a relaxation of the PV markets and the cost reductions achieved on the learning curve in the meantime factored in again. Furthermore, the cost decrease has been stimulated by the increasing globalization of the PV market, especially the stronger market appearance of Asian manufacturers.
- The investment costs of wind onshore power plants are currently (2010) in the range of 1350 \in /kW_{el} and 1685 \in /kW_{el} and thereby slightly lower than in the previous year. Two major trends have been characteristic for the wind turbine development for a long time: While the rated capacity of new machines has increased steadily, the corresponding investment costs per kW dropped. Increases of capacity were mainly achieved by up-scaling both tower height and rotor size. The largest wind turbines currently available have a capacity of 5 to 6 MW and come with a rotor diameter of up to 126 meters. The impact of economies of scale associated with the turbine upscaling on turbine cost is evident: The power delivered is proportional to the diameter squared, but the costs of labour and material for building a turbine larger are constant or even fall with increasing turbine size, so that turbine capacity increases disproportionally faster than costs increase. From around 2005 on the investment costs have started to increase again. This increase of investment cost was largely driven by the tremendous rise of energy and raw material prices as observed in recent years, but also a move by manufacturers to improve their profitability, shortages in certain turbine components and improved sophistication of turbine design factored in.

For RES-H plants as displayed in Table 5 the distinction between grid-connected and nongrid heating systems is important. Among the first category are biomass and geothermal district heating systems and among the latter one biomass non-grid heating systems, solar thermal heating systems and heat pumps. Depending on the scale investment costs for biomass district heating systems currently range between $380 \notin kW_{heat}$ and $580 \notin kW_{heat |}$ and for geothermal district heating systems between $820 \notin kW_{heat}$ and $2160 \notin kW_{heat}$. In case of non-grid biomass heating systems the investment costs differ depending on fuel type between $390 \notin kW_{heat}$ and $685 \notin kW_{heat}$. Heat pumps currently cost from $735 \notin kW_{heat}$ up to $1195 \notin kW_{heat}$ and for solar thermal heating systems depending on scale the specific investment costs reach from $660 \notin kW_{heat}$ to $880 \notin kW_{heat}$.

Table 7 provides the current investment cost data for biofuel refineries. With regard to the fuel input / output different plant types are included in the database. Biodiesel plant (FAME) currently cost from $205 \notin /kW_{trans}$ to $835 \notin /kW_{trans}$, bio ethanol plants from $605 \notin /kW_{trans}$ to $2150 \notin /kW_{trans}$ and BTL plant from $825 \notin /kW_{trans}$ to $6190 \notin /kW_{trans}$. Please note that in the case of advanced bio ethanol and BtL the expressed cost and performance data represent expected values for the year 2015 - the year of possible market entrance with regard to both novel technology options.

RES-H sub-	Plant	Investment costs	O&M costs	Efficiency (heat) ¹	Lifetime (average)	Typical plant size		
category	specification	$\left[\mathcal{E}/kW_{heat} \right]^2$	[€/(kW _{heat} *yr)] ²	[1]	[years]	$[MW_{heat}]^2$		
Grid-connected heating systems								
Diamaga	Large-scale unit	380 - 390	19 – 20	0.89	30	10		
BIOMASS -	Medium-scale unit	420 - 460	21 – 23	0.87	30	5		
uistrict fieat	Small-scale unit	500 - 580	24 – 27	0.85	30	0.5 - 1		
Caatharmal	Large-scale unit	820 - 840	50 – 52	0.9	30	10		
Geothermal -	Medium-scale unit	1490 – 1520	55 – 56	0.88	30	5		
uistrict fieat	Small-scale unit	2145 – 2160	56 – 59	0.87	30	0.5 - 1		
<u>Non-grid hea</u>	ting systems							
D:	log wood	390 - 430	12 – 15	0.75 - 0.85*	20	0.015 - 0.04		
Biomass -	wood chips	525 – 675	14 – 17	0.78 - 0.85*	20	0.02 - 0.3		
non-griu neat	Pellets	510 - 685	11 – 15	0.85 - 0.9*	20	0.01 - 0.25		
llest numns	ground coupled	735 – 1215	5.5 - 7.5	3 - 4 ¹	20	0.015 - 0.03		
Heat pumps	earth water	800 - 1195	10.5 - 18	3.5 - 4.5 ¹	20	0.015 - 0.03		
Solar thermal	Large-scale unit	$660 - 680^2$	9 - 10 ²	-	20	100 - 200		
heating & hot	Medium-scale unit	$760 - 780^2$	11 - 15 ²	-	20	50		
water supply	Small-scale unit	860 - 880 ²	15 - 17 ²	-	20	5 - 10		

Table 5: Overview on economic-& technical-specifications for new RES-H plant (grid & non-grid) (for the year 2010)

<u>Remarks:</u>

¹ In case of heat pumps we specify under the terminology "efficiency (heat)" the *seasonal performance factor* - i.e. the output in terms of produced heat per unit of electricity input

² In case of solar thermal heating & hot water supply we specify under the investment and O&M cost per unit of m² collector surface (instead of kW). Accordingly, expressed figures with regard to plant sizes are also expressed in m² (instead of MW).

RES-E		Investment	0&M	Efficiency	Efficiency	Lifetime	Typical
sub-	Plant specification	costs	COSTS	(electricity)	(heat)	(average)	plant size
category		[€/kW _{el}]	[€/(kW _{el} * year)]	[1]	[1]	[years]	[MW _{el}]
	Agricultural biogas plant	2890 - 4860	137 - 175	0.28 - 0.34	-	25	0.1 - 0.5
	Agricultural biogas plant - CHP	3120 - 5085	143 – 182	0.27 - 0.33	0.55 - 0.59	25	0.1 - 0.5
Piogos	Landfill gas plant	1445 - 2080	51 – 82	0.32 - 0.36	-	25	0.75 - 8
DIUgas	Landfill gas plant - CHP	1615 - 2255	56 - 87	0.31 - 0.35	0.5 - 0.54	25	0.75 - 8
	Sewage gas plant	2600 - 3875	118 – 168	0.28 - 0.32	-	25	0.1 - 0.6
	Sewage gas plant - CHP	2775 - 4045	127 – 179	0.26 - 0.3	0.54 - 0.58	25	0.1 - 0.6
	Biomass plant	2540 - 3550	97 – 175	0.26 - 0.3	-	30	1 – 25
Piomass	Cofiring	350 - 580	112 – 208	0.35 - 0.45	-	30	-
DIOITIdSS	Biomass plant - CHP	2600 - 4375	86 – 176	0.22 - 0.27	0.63 - 0.66	30	1 – 25
	Cofiring – CHP	370 - 600	115 – 242	0.20 - 0.35	0.5 - 0.65	30	-
Diouvasta	Waste incineration plant	5150 - 6965	100 - 184	0.18 - 0.22	-	30	2 – 50
BIOWASIE	Waste incineration plant - CHP	5770 - 7695	123 – 203	0.16 - 0.19	0.62 - 0.64	30	2 – 50
Geothermal electricity	Geothermal power plant	2335 - 7350	101 - 170	0.11 - 0.14	-	30	5 – 50
	Large-scale unit	1600 - 3460	33 - 36	-	-	50	250
Hydro large-	Medium-scale unit	2125 – 4900	34 – 37	-	-	50	75
scale	Small-scale unit	2995 - 6265	35 – 38	-	-	50	20
	Upgrading	870 – 3925	33 - 38	-	-	50	-
	Large-scale unit	1610 - 3540	36 - 39	-	-	50	9.5
Hydro small-	Medium-scale unit	1740 - 5475	37 – 40	-	-	50	2
scale	Small-scale unit	1890- 6590	38 - 41	-	-	50	0.25
	Upgrading	980 - 3700	36 - 41	-	-	50	-
Photovoltaics	PV plant	2875 - 3480	30 - 39	-	-	25	0.005 - 0.05
Solar thermal electricity	Concentrating solar power plant	4135 - 5140	136 - 200	0.33 - 0.38	-	30	2 – 50
	Tidal (stream) power plant - shoreline	6085 - 7100	95 – 145	-	-	25	0.5
lidal stream	Tidal (stream) power plant - nearshore	6490 - 7505	108 – 150	-	-	25	1
energy	Tidal (stream) power plant - offshore	6915 - 8000	122 – 160	-	-	25	2
	Wave power plant - shoreline	5340 - 5750	83 - 140	-	-	25	0.5
Wave energy	Wave power plant - nearshore	5785 - 6050	90 - 145	-	-	25	1
	Wave power plant - offshore	7120 – 7450	138 – 155	-	-	25	2
Wind onshore	Wind power plant	1350 - 1685	30 - 36	-	-	25	2
	Wind power plant - nearshore	2850 - 2950	64 – 70	-	-	25	5
Wind	Wind power plant - offshore: 530km	3150 - 3250	70 – 80	-	-	25	5
offshore	Wind power plant - offshore: 3050km	3490 - 3590	75 – 85	-	-	25	5
	Wind power plant - offshore: 50km	3840 - 3940	80 - 90	-	-	25	5

Table 6: Overview on economic-& technical-specifications for new RES-E plant (for the year 2010)

RES-T sub- category	Fuel input	Investment costs	O&M costs [€/(kW _{trans} *	Efficiency (transport)	Efficiency (electricity)	Lifetime (average)	Typical plant size
		[t/KVV trans]	year)]	[1]		[yeurs]	[IVI VV trans]
Biodiesel plant (FAME)	rape and sunflower seed	205 – 835	10-41	0.66	-	20	5 - 25
Bio ethanol plant (EtOH)	energy crops (i.e. sorghum and corn from maize, triticale, wheat)	605 - 2150	30 - 142	0.57 - 0.65	-	20	5 - 25
Advanced bio ethanol plant (EtOH+)	energy crops (i.e. sorghum and whole plants of maize, triticale, wheat)	1245 - 1660 ¹	57 -74 ¹	0.58 - 0.65 ¹	0.05 - 0.12 ¹	20	5 - 25
BtL (from gasifier)	energy crops (i.e. SRC, miscanthus, red canary grass, switchgrass, giant red), selected waste streams (e.g. straw) and forestry	825 - 6190 ¹	38 - 281 ¹	0.36 -0.43 ¹	0.02 - 0.09 ¹	20	50 - 750

Table 7: Overview on economic-& technical-specifications for new biofuel refineries (for the year 2010)

Remarks:

¹ In case of Advanced bio ethanol and BtL cost and performance data refer to 2015 - the year of possible market entrance with regard to both novel technology options.

While the investments costs of RES technologies as described above are suitable for an analysis at the technology level, for the comparison of technologies the generation costs are relevant. Consequently, the broad range of the resulting generation costs, due to several influences, for several RES technologies is addressed subsequently. Impacts as, variations in resource- (e.g. for photovoltaics or wind energy) or demand-specific conditions (e.g. full load hours in case of heating systems) within and between countries as well as variations in technological options such as plant sizes and/or conversion technologies are taken into account. In this context, for the calculation of the capital recovery factor a payback time of 15 years, which represents rather an investor's view than the full levelized costs over the lifetime of an installation, and weighted average cost of capital of 6.5% are used.

As can be observed from Figure 5, Figure 6 and Figure 7 the general cost level as well as the magnitude of the cost ranges vary strongly between the different technologies. It is thereby striking that RES-H options under favourable conditions are either competitive or close to competitiveness, while all RES-T options still are above the market price. Looking at RES-E options the situation is more diverse. The most conventional and cost efficient options like large hydropower and biogas can generate electricity below market prices. It is also noticeable that wind power (onshore) cannot deliver electricity at market prices even at the best sites. Of course, this proposition holds only for current market prices which have decreased substantially in the wholesale market in the near past. For most RES-E

technologies the cost range at the EU level appears comparatively broad. In the case of PV or wind energy this can be to a lesser extent ascribed to (small) differences in investment costs between the Member States, but more crucial in this respect are the differences in resource conditions (i.e. the site-specific wind conditions in terms of wind speeds and roughness classes or solar irradiation and their formal interpretation as feasible full load hours) between the Member States. In the case of photovoltaics the broad cost range results also from differences in terms of application whereby the upper boundary refers to facade-integrated PV systems.



Figure 5: Long-run marginal generation costs (for the year 2010) for various RES-E options in EU countries



Figure 6: Long-run marginal generation costs (for the year 2010) for various RES-H options in EU countries



Figure 7: Long-run marginal generation costs (for the year 2010²) for various RES-T options in EU countries

4 Energy demand scenarios

In the past several methods have been developed to predict future energy demand. Traditionally, methods such as time series analysis, regression or econometric analysis and ARIMA techniques were used extensively. Also soft computing techniques such as fuzzy logic, genetic algorithm and neural networks have been used to develop demand side scenarios. New techniques comprise support vector regression and ant colony / particle swarm optimization methods, which were adopted for energy demand forecasting. Finally, traditional bottom up models serve to predict future demand. A comprehensive overview of methods used in energy demand forecasting is presented in (Suganthi und Samuel 2012).

Those methods have been applied to several energy sectors, e.g. the coal, gas, oil and the electricity sector. Furthermore, in some analyses even just part of a sector has been analysed (cf. industrial vs. residential electricity consumption). Another distinctive feature of energy demand predictions is the forecast horizon. The suitability of a certain method depends on the one hand on the availability of data series for the underlying input parameter (historic and predictions) and on the other hand on the forecast horizon to be considered. In the past, a number of studies developed energy forecasts for Turkey (Kankal u. a. 2011). Most of these studies focus on the prediction of the future demand for electricity on a yearly basis up to a time horizon to 2025. The methods applied mostly comprise artificial neural networks and genetic algorithm approaches and are very suitable to explain characteristic historic patterns in energy demand and to apportion them among the near future. However, the aim of this task is to develop long-term expectations for the development of the demand for energy and in particular for electricity. Within the time range up to 2050 no reliable forecasts can be developed rather than a number of consistent scenarios based on forecasts of a number of distinctive input parameters. Consequently, within this study an econometric approach is used that has been widely applied in energy demand modelling (Zarnikau 2003) and the results are put into relation to the scenarios of other studies. To derive comparable elasticities an adapted version of the production

² In the case of advanced bio ethanol and BtL cost and performance data refer to 2015 - the year of possible market entrance with regard to both novel technology options.

function standard form, first applied by (Houthakker 1951), has been chosen as energy demand function (cf. equation 1).

$$E_t = C \cdot POP_t^{\alpha} \cdot Y_t^{\beta(Y)} \cdot \frac{1}{(1-\varepsilon_t)}$$
(1)

- *E_t* ... Total primary energy demand in year t [mtoe]
- C ... Constant term
- POP_t ... Population in year t [1]
- Y_t ... Real gross domestic product per capita in year t [US\$2005]
- α ... Population elasticity of energy demand
- β ... Income elasticity of energy demand
- ε_t ... Energy efficiency ratio function

As can be seen in (1) it is assumed that the energy demand is subject to two main independent socio-economic parameters. Similar to previous studies these parameters comprise the population and the income per capita, which is measured in real terms. The energy demand increases with the number of inhabitants and their disposable income. It has been proven that there is a direct relationship between living standards and energy consumption. Other parameters influencing the energy demand are the amount of import and export, the labour force, energy efficiency measures and energy prices. Due to the fact that long-term forecasts of those parameters are in the same range of uncertainty than the variable to be explained and for the sake of simplicity, it has been chosen not to integrate them into the energy demand function. This implicitly means that those terms are supposed to remain constant over time and do neither have an explaining character in the past, nor an influence in future scenarios. Due to the broad variation of the two remaining parameters and the resulting spread in the scenarios this can be considered not to be a major drawback of the approach. The impact of energy efficiency measures has been considered via a predetermined energy efficiency trend function (cf. Figure 13).

Another aspect of importance is that structural changes within a country have to be considered in estimating the future energy demand. For example, in the last decade the living standard of lots of people in Turkey increased and this trend is probable to continue. Also, the trend towards the establishment of large industries in Turkey leads to a more energy-intensive production structure. Therefore, it would be insufficient to extrapolate the regression parameters of the test period into the future. To integrate these issues into the energy demand function the income elasticity is supposed to increase proportionally to the growth of the GDP per capita (2).

$$\beta(Y_t) = \beta_0 + \delta \cdot \Delta Y_t \tag{2}$$

 β ... Income elasticity of energy demand in year t

 β_0 ... Income elasticity resulting from the regression analysis of the test period

 ΔY_t ... Growth of real gross domestic product per capita between year t and t-1

 δ ... Scaling factor function

In order to perform a multiple linear regression, equation (1) is logarithmized to build the log-linear standard form (3).

$$\ln E_t = \ln C + \alpha \cdot \ln POP_t + \beta(Y_t) \cdot \ln Y_t - \ln(1 - \varepsilon_t)$$
(3)

Historic values for GDP and population have been collected from (TURKSTAT 2013). Data on historic energy consumption stems from the Turkish Ministry of Energy and Natural Resources (MENR 2009a) as well as (EUROSTAT 2013). The test period for the regression analysis have been chosen from 1960 up to 2007. Within the years 2008 to 2012 the Turkish economy suffered from the international financial crisis and therefore this period constitutes a structural break in the dataset and thus has not been considered within the regression. For the regression is has been assumed that no energy efficiency measures have been implemented so far and thus the energy efficiency ratio ε was set to zero. In Figure 8 the historic values, assumed scenarios and corresponding growth rates for the real GDP of Turkey up to 2050 are illustrated. The basic methodology for forecasting the GDP is based on (Hawksworth 2006) and have been adopted within the frame of the AMPERE project (Kriegler 2011).



Figure 8: Historic and assumed GDP of Turkey up to 2050 according to two scenarios

Formally the GDP is described as a Cobb-Douglas production function (4).

$$Y_t = A_t \cdot K_t^a \cdot L_t^{1-a} \tag{4}$$

- A_t ... Total factor productivity in year t
- K_t ... Physical capital stock in year t
- L_t ... Quality adjusted input of labour in year t
- *a* ... Share of capital in total nation income (a = 1/3)

The input parameters are based on future estimations on international developments and comparisons between similar regions. The two selected scenarios reflect the two extreme scenarios, which differ on the one hand in their expectations on the future development of developed countries in general and on the other hand in the presumed time of convergence rate of developing countries to the OECD average values.

The projections on future population were taken from (TURKSTAT 2013). The baseline and the most optimistic scenario³ have been selected for this study.



Figure 9: Historic and assumed population of Turkey according to two scenarios

Based on this input data, four future energy demand scenarios have been developed via the application of the regression model in (1) (cf. Figure 10). The *high-scenario* corresponds to the *high scenarios* of each GDP per capita and the population forecast. The *low-scenario* is linked to the *low scenario* of GDP per capita and the low scenario of

³ The baseline scenario assumes that the total fertility rate decreases to its lowest value of 1.65 in 2050, whereas in the high scenario it is assumed that the fertility rate will increase up to 3 in 2050.

population forecast. The efficiency scenarios *high-eff* and *low-eff* additionally consider the energy efficiency ratio depicted in Figure 13. These trends were derived from the difference in the EU27 average values of the *PRIMES baseline scenario* (PRIMES 2011a) and the *PRIMES energy efficiency scenario* (PRIMES 2011b). Additionally, two comparative scenarios have been plotted in Figure 10. On the one hand the MENR scenario (WEC 2012) represents an official scenario of the Turkish Regional Committee of the World Energy Council and on the other hand the OME scenario (Karbuz 2013) developed by the Observatoire Méditerranéen de l'Energie, which is far more optimistic. It can be seen that there is a good overlap of the spread of comparative scenarios and those developed in this study.



Figure 10: Historic and assumed gross energy demand of Turkey up to 2050 according to several scenarios

The development of electricity demand scenarios has been broken down in the development of scenarios for the electricity consumption per capita (cf. Figure 11). The underlying assumption is that the development of the average values of South European countries EU-S (Portugal, Spain, Italy, and Greece) surf as a reference value for the future consumption of Turkey. The average levels up to 2050 are based on the results of (PRIMES 2011a).

The scenarios differ in their assumptions on how the demand development in Turkey relates to the reference values. The *low scenario* assumes that Turkey's electricity consumption per capita will converge with the reference values of EU-S by 2040 and will continue to grow inline with these values up to 2050. In the case of the *high scenario* it has

been assumed that a fast penetration of electric appliances will occur in Turkey and its consumption per capita will overshot EU-S average values in 2022. In the following period up to 2050 the demand per capita converges to an average value of heavily industrialized countries. The share of electricity on gross energy demand increases in both scenarios from 18% in 2011 up to 28-32% in 2050. In case of the *high scenario* this share is temporary slightly overshot and reaches 27% in 2025. To derive the energy efficiency scenarios *Low-eff* and *High-eff* the corresponding baseline scenarios have again be adjusted by the electric energy efficiency scenario in Figure 13.

Finally, the gross electricity demand scenarios in Figure 12 are calculated via the multiplication of the electricity consumption scenarios per capita with the two population scenarios in Figure 9. As before, only extreme cases were considered, which means that only high scenarios were multiplied with high scenarios and vice versa.



Figure 11: Historic and assumed gross electricity consumption per capita according to several scenarios compared to the PRIMES 2011 reference scenario of the EU27

Those scenarios have been compared to a number of other studies that have analyzed future electricity demand for Turkey. In general, the scenarios developed in this study represent the full range of expectations on future electricity demand. The most prominent studies are the high and low demand forecast of TEIAS (TEIAŞ 2011), the national transmission grid operator, and some others (Hamzaçebi 2007), Akay und Atak 2007), which represent the upper band of scenarios. Also on the lower range of the spectrum are the forecasts of a number of studies from the relevant literature (Dilaver 2011), (Kücükdeniz

2010), (Kavaklioglu et.al. 2009). The *low scenario* exactly matches the TEIAS low demand scenario that has been developed up to 2021.



Gross electricity demand [GWh]

Figure 12: Historic and assumed gross electricity consumption of Turkey up to 2050 according to several scenarios

Efficiency ratio



Figure 13: Assumed energy efficiency trends up to 2050 based on the difference of the PRIMES 2011 reference scenario and the PRIMES 2011 energy efficiency scenario of the EU27

The future demand for the transport sector has been estimated based on the methodology proposed in (Ceylan 2008). The demand function depends on the future development of the GDP, the population and an arbitrary parameter reflecting the equivalent amount of vehicle-kilometer driven by all transport modes and per year (5). Accordingly to the other cases before, an efficiency demand scenario has been derived via applying the efficiency ratio depicted in Figure 13.

$$E_t^T = 1.7727 \cdot GDP_t^{0.1822} + 0.3796 \cdot POP_t^{0.7974} + 0.4525 \cdot Vkm_t^{0.9297} + 4.2140$$
(5)

- E_t^T ... Total energy demand for the transport sector in year t [mtoe]
- GDP_t ... Real gross domestic product in year t [10^9 US\$2005]
- POP_t ... Total population in year t [x10^6]
- Vkm_t ... Equivalent number of vehicle-kilometer driven in year t [x10^9 km]

The demand for heat fills the gap in between the sum of the demand for electricity plus transport and the total energy demand. From all developed scenarios we assume the *low scenario* to be the one with the highest probability. Therefore, we will consider this scenario as our reference scenario within all further analyses of WP5. Additionally, we will include the *low-eff* scenario to reflect an example with high energy efficiency efforts and to contrast the reference case. The final scenarios are shown in Figure 14 and Figure 15.



Figure 14: Reference energy demand scenario of Turkey by sector





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6 ANNEX 1 – References used in the assessment of the RES potential

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