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Renewable energy: past trends and future growth in 2 degrees scenarios

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Abstract

This study explores past growth rates of renewable energy sources (1971-2012) and required future ones in 2 degrees scenarios. Results show that in spite of comparatively high growth of renewable energy in the period 2000-2012, the share of renewable energy in total energy use stayed the same (13%). The overall increase in renewable energy amounted to 2.2%/yr in the period 1971-2012 and 2.6%/yr in the period 2000-2012. In order to be consistent with a 2 degrees pathway the growth rate would need to increase to 3-5%/yr. Especially high growth would be required for wind, solar and geothermal (~10%/yr). This would lead to a change in the mix of renewable energy used, with a much higher share of variable renewable energy sources. However most notable is the strong difference in the growth of energy use, compared to past trends. Primary energy use needs to consistently decrease by 0.1-0.5%/yr for OECD regions, up to 2050, which would require a breach from past trends. But especially for non-OECD regions the needed change is large. Regional growth rates for energy use in the period 2000-2012 range from 1.5%/yr to 6.1%/yr and should decrease to the range of -0.2%/yr to 0.9%/yr.

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Keywords: Renewable Energy; Growth Rates; Trends; 2 degrees scenarios

1. Introduction

Many studies agree that a transition to a sustainable energy supply is needed in order to safeguard the supply of energy for future generations and abate greenhouse gas emissions. Limiting the average global surface temperature increase to 2°C, compared to pre-industrial average, is often regarded as an adequate means of avoiding dangerous

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climate change [1]. In many scenarios that envision a development of energy supply that would be in line with a 2 degrees target, a large component of the solution consists of renewable energy and energy efficiency [2]. Renewable energy would be in the range of 200-300 EJ in 2050, equivalent to 40-80% of total primary energy supply in 2050. This means an increase by a factor of 3 compared to 74 EJ in 2012 [3]. However, in spite of a significant increase in the use for renewable energy in the period 2000 to 2012 (from 54 EJ to 74 EJ), the share of renewable energy in total energy use has remained at 13% [3]. A reason can be found in the growth of total energy use and hence non-renewable energy use, which increased likewise. Of renewable energy globally, biomass is at the moment the largest source used, equivalent to 10% of total primary energy use in 2012, followed by hydro power, responsible for 2% [3]. A transition of energy supply in order to help achieve a 2 degrees target requires a strong growth of renewable energy and energy-efficiency both in absolute and relative sense. Also a strong shift is needed to other renewable energy sources than biomass and hydro. Many studies have assessed the increases in renewable energy that would be needed in many different scenarios [e.g. 2, 4, 5]. A comparison with past trends on a regional basis is, as far as known, not available yet. This paper hence explores past growth rates for different types of renewable energy and required future ones in 2 degrees scenarios. For this purpose past trends in renewable energy use in the period 1971 to 2012 are analysed and future contributions are explored (section 2). This period shows the emergence of solar, wind and geothermal energy, and biomass use for transport fuels and electricity generation. In section 3, future contributions are assessed of renewable energy use in 2 degrees scenarios, on a regional basis. Lastly, discussion and conclusions are given in section 4.

2. Past trends in renewable energy use

The development of renewable energy by type and country is based on the IEA Extended Energy Balances [3]. Primary energy use in this data source is based on the physical energy content method, which means that for wind and solar energy the amount of primary energy is equal to the amount of final energy. For biomass electricity a conversion efficiency of 33% is used and for geothermal electricity an efficiency of 10%.

Fig. 1 shows the development of global primary energy use in the period 1971-2012 (a) and of renewable energy use excluding biomass and hydro (b), respectively. Overall renewable energy use more than doubles from 30 EJ in 1971 to 74 EJ in 2012. The share of biomass in renewable energy use slowly decreases from 85% in 1971 to 73% in 2012. This is mainly a result of an increasing share of hydro from 14% to 18% and an increase in geothermal energy use from 1% to 4%. Fig. 1 (b) shows the emergence of solar thermal energy (mainly after 1990) and wind power (after 2000), which account for 1% and 2% of renewable energy use, respectively in 2012.

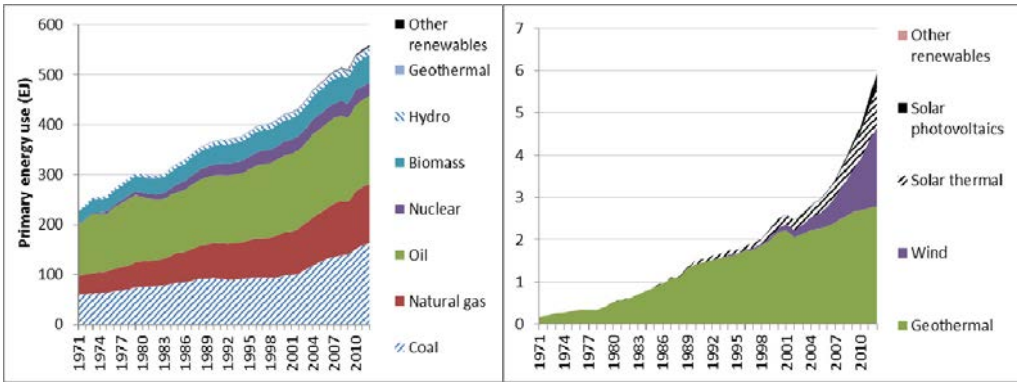

Fig. 1 (a) global primary energy use from 1971-2012 and (b) global renewable energy supply from 1971-2012, excluding biomass and hydro (based on [3])

Table 1 shows compounded annual growth rates of renewable energy (RE) for four decades and for the overall period 1971-2012. Growth rates can be used to express the deployment level (see e.g. [6] and [4]) and seen as indicators of the pressure on infrastructures that are required to support the technologies. There is a clear increase in the growth rates after 2000, when energy and climate policies take effect. Visible is the entrance of wind and solar

thermal in the eighties and of solar PV in the nineties. In spite of the higher growth rates after 2000, the share of renewable energy in total primary energy use has only increased marginally during the period 1971-2012, from 13.0% to 13.5%. Although growth rates of renewable energy use increased from 1.5%/yr in the period 1990-2000 to 2.6%/yr in the period 2000-2012, non-renewable energy (especially coal and natural gas) experienced a similar increase in growth rates from 1.4%/yr to 2.3%/yr.

Table 1. Yearly growth rates (%) per period per energy source and for total primary energy use (based on [3])

	1971-1980	**1980-1990**	**1990-2000**	**2000-2012**	***1971-2012***
Biomass	2.1	1.8	1.2	2.2	*1.8*
Hydro	4.0	2.2	2.0	2.9	*2.7*
Geothermal	12.8	10.6	4.4	2.1	*7.0*
Wind		79.6	23.2	26.4	
Solar thermal		53.1	9.8	13.2	
Photovoltaics			46.9	46.7	
Tide, wave and ocean	-0.1	1.9	0.1	-0.6	*0.0*
Renewable energy	*2.5*	*2.1*	*1.5*	*2.6*	*2.2*
Other energy use	*3.1*	*2.0*	*1.4*	*2.3*	*2.2*
Total energy use	***3.0***	***2.0***	***1.4***	***2.4***	***2.2***

Table 2 shows compounded annual growth rates for the period 2000-2012 for the IEA world regions (see [3] for definitions). Strong regional differences in growth rates are present per source. The category Solar/Wind/Other shows by far the strongest growth with 21%/yr, globally. For biomass, highest growth occurred in the Middle East (6.1%) and OECD Europe (5.6%/yr). The overall growth for biomass was moderate with 2.2%/yr. Hydro power growth was highest in China with 12%/yr, same as geothermal with 9%/yr and solar/wind with 30%/yr. Due to a low growth rate of biomass in China (0.5 %/yr), the overall renewable energy growth rate however was more moderate with 2.9%/yr. Especially when compared to the growth rate for total primary use of 7.8%/yr, leading to a decrease in the share of renewable energy from 19% in 2000 to 11% in 2012.

Table 2. Yearly growth rate and share (%) 2000-2012 for renewable energy and total primary energy use (based on [3])

	Bio-mass	**Hydro**	**Geo-thermal**	**Solar/ Wind/ other**	**Total RE**	**Total Energy use**	**Share RE 2000**	**Share RE 2012**
OECD Americas	1.4	0.6	-1.8	18.6	1.4	-0.3	6.5	8.0
OECD Asia Oceania	3.3	-0.9	1.7	7.1	2.0	0.4	3.7	4.5
OECD Europe	5.5	0.1	4.7	20.9	4.7	0.0	7.3	12.7
European Union-27	*6.3*	*-0.4*	*1.6*	*22.2*	*5.6*	*-0.2*	*6.1*	*12.1*
Latin America	3.4	2.3	7.8	21.9	3.1	3.0	28.7	29.2
India	1.8	4.5	0.0	26.7	2.1	4.7	34.0	25.2
China	0.5	12.0	8.7	29.4	2.9	7.8	19.2	10.9
Middle East	6.1	8.9	0.0	7.8	7.9	5.5	0.3	0.4
Non-OECD Europe and Eurasia	2.5	0.3	16.9	27.0	1.4	1.5	3.9	3.9
Africa	2.9	3.4	11.6	26.4	2.9	3.3	51.8	49.6
Other non-OECD Asia	1.4	5.4	2.6	12.0	1.8	3.0	29.7	25.6
World	**2.2**	**2.9**	**2.1**	**20.7**	**2.6**	**2.4**	**13.0**	**13.5**

High overall renewable energy growth rates are visible in OECD Europe and Middle East. More specifically, the European Union has the highest regional RE growth rate and simultaneously a slightly decreasing amount of primary energy use. The share of renewable energy thereby increased from 6% in 2000 to 12% in 2012. The high growth rates in the Middle East are related to the very low amount (0.08 EJ) of renewable energy used (see Fig 2), amounting to only 0.4% of primary energy use in 2012, up from 0.3% in 2000. The lowest overall renewable energy growth occurred in OECD Americas and non-OECD Europe and Eurasia (1.4%/yr).

The regions with the highest shares of renewable energy in 2012 are Africa (48%), Latin America (29%) and, other non-OECD Asia and India (25%). Latin America has a high share of renewable energy use, mainly due to hydro use and biofuels. Africa and non-OECD Asia have high shares of (traditional) biomass use.

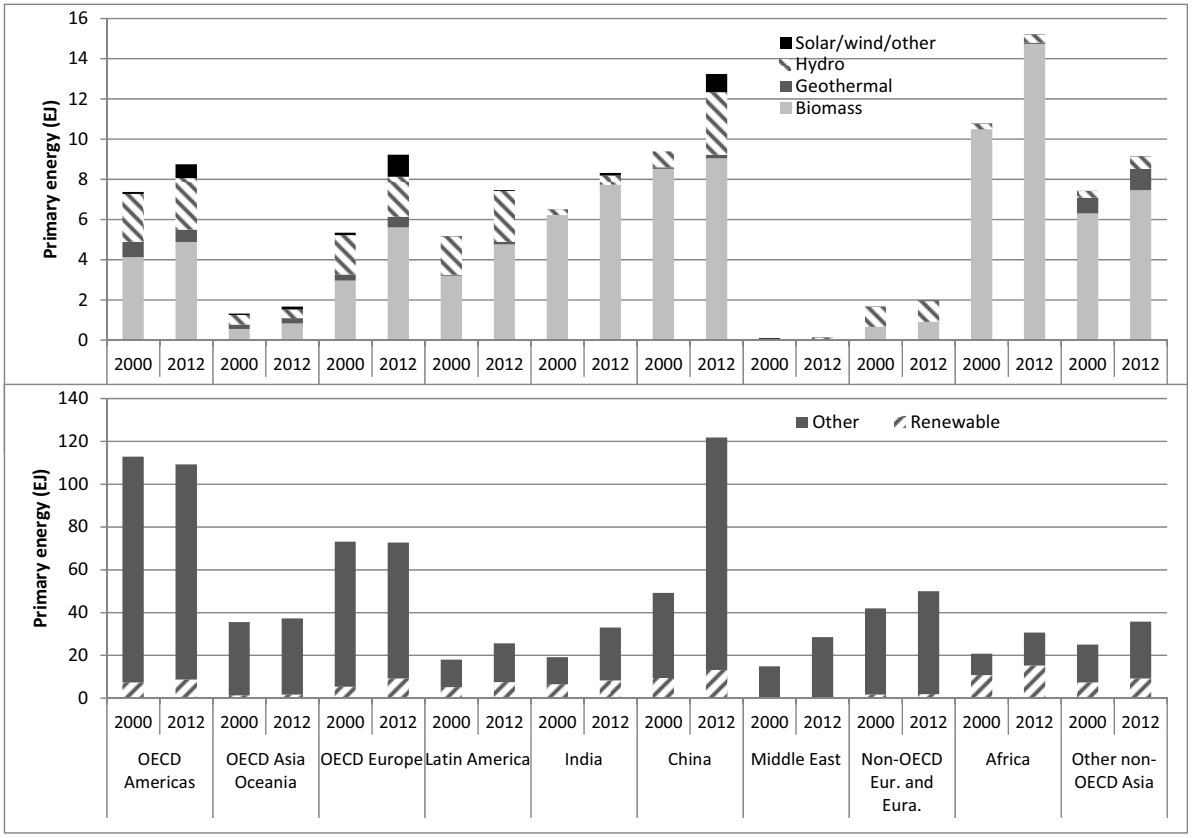

Fig 2. (a) total energy use and share renewable energy by region and (b) renewable energy use by source in 2000 and 2012 (based on [3])

3. Future contributions of renewable energy and energy-efficiency

Stabilizing greenhouse gas concentration in the air to 450 ppm would be needed to likely limit global temperature increase to 2 °C, compared to pre-industrial level [7, 8, 1]. This would correspond to an energy system consistent with an emissions trajectory where energy-related CO_2 emissions decrease globally by more than half in 2050 (compared with 2009 level) and ensuring that they continue to fall thereafter [9]. An increase in renewable energy and improvement of energy-efficiency would the key measures for reducing these emissions.

Krey and Clarke (2011) review 162 long term energy scenarios in terms of differences and similarities [4]. This study was used in the IPCC "Special Report on Renewable Energy Sources and Climate Change Mitigation" (SRRES), where 164 long term energy scenarios are evaluated [10]. These scenarios are divided into two categories "< 400 ppm" and "400-600 ppm". Since a 2 degrees target is generally related to a concentration of 450 ppm in 2050 both categories are included in this study. To complement these, available scenarios published after this study are taken into account. These are:

- IEA "Energy Technology Perspectives" (ETP), edition 2012 [9]
- Greenpeace/EREC Energy [r]evolution (ER) scenario, edition 2012 [11]
- WWF/Ecofys Energy scenario 2011 [12]
- Global Energy Assessment (GEA), Energy pathways for sustainable development [13]

These scenarios cover global energy supply and have sector detail available with a time frame up to 2050. Not included are the Shell New Lens Scenarios [14], since these do not reach a 2° C target, and the Global Environmental Outlook 5 scenarios [15], which do not include sufficient detail.

Key characteristics of the included scenarios are given in Table 3. For comparison reasons the 6 degrees scenario (6DS) of the IEA ETP is included. This is a baseline scenario that is broadly consistent with the World Energy Outlook (WEO) "Current Policies" scenario that runs up to 2035 [16]. In the GEA and ETP 2DS scenario energy related greenhouse gas emissions amount to 17 Gtonne CO_{2eq} by 2050 (compared to 59 in 2050 in the 6DS scenario). Both aim at stabilizing greenhouse gas concentration levels to 450 ppm. The Greenpeace/EREC ER scenario explores a higher level of greenhouse gas emission reduction to only 3 Gtonne. This would increase the chance of limiting global temperature increase to 2 degrees. The WWF/Ecofys scenario aims at (near) 100% renewable energy deployment and ends up with only 1 Gtonne CO_{2eq} in 2050. In terms of renewable energy deployment the ER scenario is highest with 394 EJ, compared to 219-286 in the ETP and GEA scenarios. WWF is in the middle with 247 EJ. The GEA consists of two trajectories Efficiency and Supply. The Efficiency trajectory focuses strongly on energy efficiency improvement and has a more moderate primary energy use of 530 EJ in 2050. The Supply trajectory focuses on low carbon energy supply with more renewables and more carbon capture and storage (15 Gtonne CO_2 in 2050, compared to 6 Gtonne in the Efficiency scenario).

Table 3. Key characteristics of 2° scenarios in 2050 [3, 9- 13]

Scenario	GHG energy (Gt CO_{2eq})	Global energy use (EJ)	Share RE	RES (EJ)
IEA (2014), year *2012*	32	560	13%	74
IPCC SRRES < 400 pm	NA	NA	NA	190-350
IPCC SRRES 400-600 ppm	NA	NA	NA	140-190
IEA ETP 2DS	17	697	41%	286
IEA ETP 6DS	59	880	15%	132
Greenpeace/EREC *ER 2012*	3.1	481	82%	394
WWF/Ecofys	0.9	260	95%	247
GEA Efficiency	17	530	41%	219
GEA Supply	17	754	38%	286

Fig 3 shows the absolute and relative amount of renewable energy use in the scenarios and the composition. A clear shift is visible in the dominance of biomass in 2012 to much higher contributions of mainly wind and solar energy. In most scenarios, biomass remains the largest renewable energy source in 2050, except for the ER scenario, where solar amounts to 105 EJ in 2050, compared to 72 EJ for biomass. The growth of biomass would be mainly in biomass electricity and biofuels [9, 11-13]. Hydro power does not show a large increase in the scenarios. The amount of wind ranges from 20-50 EJ in 2050 and for a considerable part (20-30%) consists of offshore wind [9, 11-13]. The contribution of solar energy is in most scenarios higher than wind with 10-105 EJ, with about 30% consisting of photovoltaics. The role of tide, wave and ocean energy remains limited.

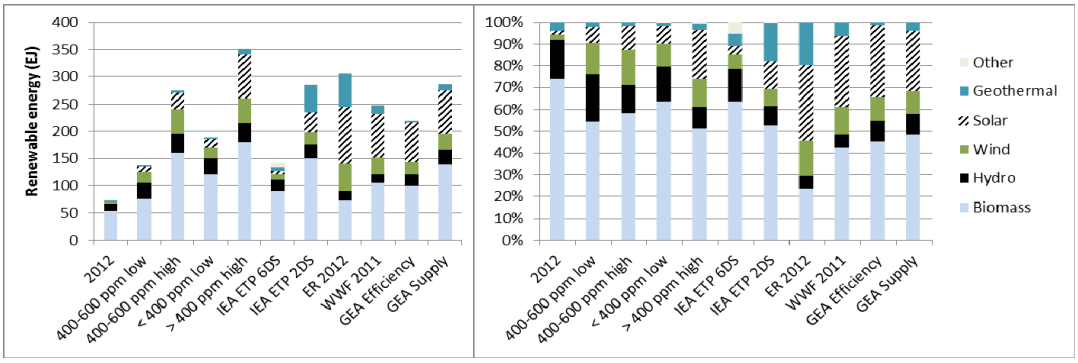

Fig 3. (a) renewable energy use per scenario in 2050, absolute and (b) relative (derived from [3, 9- 13])

In Table 4 the yearly growth rates of renewable energy in the scenarios are compared to the past growth rates from Table 1. The baseline scenario IEA ETP 6DS is included [9] and the range of the 2 degrees scenarios is

included [11-13]. Remarkable is that even the baseline ETP 6DS scenario contains a much lower growth in energy use in the period 2011-2050 than in the past (1.2% compared to 2.2% per year for primary energy use). The 2 degrees scenarios all have an even much lower development ranging from negative growth (decrease) to a very moderate growth of 0.6% per year for primary energy use. The growth rates for renewable energy are in the range of 3-5% in the 2 degrees scenarios compared to 2% in the past. This means a quite stronger uptake of renewables, even compared to the period 2000-2012, which showed a relatively high growth rate of 2.6% per year. Renewable energy sources with high growth rates in the range of 10% per year in the 2 degrees scenarios are wind (especially wind offshore), geothermal electricity, solar heat, PV and CSP and ocean energy.

All in all, renewable energy grows much faster than primary energy use in all 2 degrees scenarios and even in the baseline 6 degrees scenario. This is a clear difference with past trends where only a slightly higher growth of renewable energy in comparison to primary energy use occurred after 2000.

Table 4. Yearly growth rates (%) of renewable energy by period[I]

	'71-'80	'80-'90	'90-2000	2000-2012	*ETP 6DS (2011-2050)*	*2 °C (from base year to 2050)*
Biomass	2.0	1.9	1.1	2.2	1.3	1-3
Electricity	3	11	2	9	4.0	5-8
Biofuels			1	1	3.0	5-7
Hydro	4.0	2.2	2.0	2.9	1.3	0.4-2.7
Wind		80	23	26	5	7-10
Onshore	NA	NA	NA	NA	4	6-8
Offshore	NA	NA	NA	NA	10	14-16
Geothermal energy	13	11	4	2	3	3-8
Electricity	13	10	4	3	5	7-12
Heat	13	11	4	2	2	4-8
Solar		53	10	16	5	7-13
Heat		53	10	13	2	8-11
Photovoltaics			47	47	6	11-14
CSP[II]				20	15	21-24
Tide, wave and ocean			47	47	15	17-24
Total RE	2.4	2.2	1.5	2.6	1.6	3-5
Total primary energy use	3.0	2.0	1.4	2.4	1.2	-1.9-0.6
Share RE in primary (%)	13	13	13	13	15[III]	41-95 [III]

[I] 1971-2012 based on [3], ETP [9] and 2 degrees [11-13], [II] CSP = Concentrated Solar Power (electricity), [III] in 2050

Table 5 shows regional growth rates for primary energy use, renewable energy use and the share of renewable energy in total primary energy use for the years and period between 2000, 2012 and 2050. The future growth rates are based on the average growth rates per region for four selected scenarios in the IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [10]. These values are consistent with the lower end growth rates in the 2 degrees scenarios as presented in Table 4. From this table it is clear that the needed change in primary energy use is much stronger than the change in renewable energy growth rates. The OECD regions all need negative growth rates for primary energy use while most non-OECD regions can afford a limited increase up to 0.8%/yr.

In term of renewable energy, for most regions much higher growth rates are needed for a long time period (~40 years) then occurred in the last 12 years. The exception is OECD Europe and Latin America, where past overall renewable energy growth outnumbers the future one. The biggest increase in renewable energy uptake would be needed in non-OECD Europe and Eurasia (5.7%/yr compared to 1.4%/yr), OECD Americas (3.8%/yr compared to 1.4%/yr) and OECD Asia Oceania (5.0%/yr compared to 2.0%/yr). The combination of limited growth of primary energy and increased use of renewable energy leads to increasing shares of renewable energy of 35%-40% for OECD regions and 36-68% for non-OECD regions in 2050.

Table 5. Growth rates (%) for primary energy use, renewable energy use and the share of renewable energy in total primary energy use (based on [3] and [10])

	Total primary energy use (%/yr)		Renewable energy (%/yr)		Share of renewable energy in total primary energy use		
	2000-2012	2012-2050	2000-2012	2012-2050	2000	2012	2050
OECD Americas	-0.3	-0.2	1.4	3.8	6.5	8.0	36
OECD Asia Oceania	0.4	-0.6	2.0	5.0	3.7	4.5	35
OECD Europe	0.0	-0.1	4.7	3.0	7.3	12.7	40
Latin America	3.0	0.8	3.1	2.8	28.7	29.2	61
Middle East	5.5	0.1	7.9	13.2	0.3	0.4	46
Non-OECD Europe Eurasia	1.5	-0.3	1.4	5.7	3.9	3.9	36
Africa	3.3	0.7	2.9	1.5	51.8	49.6	68
Non-OECD Asia	6.1	0.1	2.3	3.4	29.7	25.6	55
World	**2.4**	**0.0**	**2.6**	**3.3**	**13.0**	**13.5**	**48**

4. Discussion and conclusions

This paper focused on two parts: first the development of past trends and growth rates of renewable energy in the period 1971-2012 and second on the needed growth in order to be consistent with a 2 degrees pathway. From the analysis of past trends it became clear that in spite of comparatively high growth of renewable energy in the period 2000-2012, the share of renewable energy only increased slightly due to a similar increase in non-renewable energy use. Only a few regions managed to increase the share of renewable energy in their fuel mix. Most notably in the European Union the share of renewable energy increased from 6% in 2000 to 12% in 2012 with slightly decreasing energy use. China and India showed decreasing shares of renewable energy due to high growth rate for total energy and hence non-renewable energy use. This suggests that in order to increase the share of renewable energy use, most challenges might be expected in non-OECD countries.

The overall increase in renewable energy amounted to 2.2%/yr in the period 1971-2012 and 2.6%/yr in the period 2000-2012. In order to be consistent with a 2 degrees pathway these growth rates would need to increase to 3-5%/yr. Especially high growth would be required for wind, solar and geothermal in the order of 10%/yr. This would lead to a change in the mix of renewable energy used, with a much higher share of variable renewable energy sources (VRES). Much has been written on the challenges of integrating these sources in the current energy infrastructures. Overall wind and solar energy use would need to increase by as much as a factor of 30-60 in 2050, in comparison to 2012 (from 3 EJ to 58-155 EJ). The share of renewable energy would be in the range of 40-80% of energy use, with the share of wind and solar amounting to 25-54% of renewable energy use. However most notable from this assessment is the strong difference in the growth of energy use, compared to past trends. In a business as usual scenario primary energy use grows from 560 EJ in 2012 to 880 EJ in 2050, while in a 2 degrees scenario average primary energy use is slightly lower than 2012 with 530 EJ in 2050. This means that for decades primary energy use needs to consistently decrease by 0.1-0.5%/yr for OECD regions. A decrease in energy use has not occurred in the past 40 years in OECD countries, except for a couple of years during a time of recession. This would therefore require a breach from past trends. But especially for non-OECD regions the needed change is large. Regional growth rates for energy use in the period 2000-2012 range from 1.5%/yr to 6.1%/yr and should decrease to -0.2%/yr to 0.9%/yr. Therefore, a main challenge, besides increasing the uptake of renewable energy, would lie in the decrease of energy use growth rates in non-OECD countries.

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