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Abstract

Renewable energy sources are sustainable, domestic and allow for diversification of resources. Given their availability and economic feasibility, they could contribute toward a reliable electricity supply for the South Caucasus region. Based on annual generation time series derived from weather data for the period 2000–2012, we analyse the availability and economic feasibility of wind power and solar photovoltaics in Armenia, Azerbaijan and Georgia. Our analysis demonstrates that electricity generation from wind and solar power is currently not economically feasible in any of the three countries. However, we demonstrate that the attractiveness of renewable energy sources improves significantly in the future if investment costs and the cost of capital can be reduced. We conclude by discussing possible benefits of an early introduction of renewable energy sources in the electricity supply of the South Caucasus region.

Introduction

The South Caucasus region is an integral part of the European energy strategy (Altmann 2007, Meister 2014), due to its substantial reserves of natural gas and oil and its geographical location along the energy transit corridor between Central Asia and Europe. Exporting gas and oil to Europe will potentially drive the economic development of the region in the near future. However, a long-term strategy for supplying the region's domestic energy demand is required to achieve sustainable economic development. Such considerations are particularly important regarding electricity: The correlation coefficient between electricity consumption and the gross domestic product (GDP) of modern national economies is usually much higher than between total primary energy consumption and GDP.

Natural gas has a dominant position in the electricity generation mix of the South Caucasus. According to the International Energy Agency (2014), it contributed approximately 58 percent of the 38 TWh of total electricity produced in the region in 2011. Just over one third of the region's electricity production is supplied by hydropower plants. With less than 1 percent of the total, electricity production from oil played only a marginal role. On a national level, the share of hydropower ranged from 13 percent in Azerbaijan to a remarkable 77 percent in Georgia in 2011. While approximately one third of Armenia's total electricity production is generated by the region's only nuclear power plant in Metsamor, nuclear power amounted to less than 7 percent of the total demand in the South Caucasus region in 2011.

From a strategic perspective, this status quo poses several problems. First and foremost, with basically only three sources of energy and a dependence on natural gas of almost 60 percent, the overall level of diversification of the electricity supply is low. Although the largest part of the region's gas consumption is currently covered by Azerbaijan's domestic resources, natural gas is also imported to the region (Shaffer 2012). With neither access to Azerbaijani gas nor any relevant resources of its own, Armenia is heavily reliant on imported natural gas (and nuclear fuel) from Russia (Danish Energy Management 2011). While so far import dependence is only a national problem, in the long run the whole region might be affected by the depletion of resources. According to Aliyev (2013), the economic exploitation of Azerbaijan's gas reserves might be limited to the next 20–30 years. Depending on Europe's appetite for gas, a shortage of resources and related price rises could occur even earlier.

Except for hydropower and a few small-scale projects, renewable energy sources (RES) are not yet contributing to electricity supply in the South Caucasus region. Renewable electricity generation however satisfies several requirements of sustainability and security of supply. Whereas carbon abatement is a global challenge, nitrogen oxide, sulfur dioxide and particulate matter emissions have an immediate impact on the environment and the health of the local population. Their reduction is an important issue in the South Caucasus, where pollution from fossil and nuclear fuels has reached disconcerting dimensions (Kochladze 2009). Replacing fossil fuels would immediately reduce the environmental impact of power generation in the region. In addition, the deployment of RES would diversify the mix of energy sources and generation technologies as well as reduce import dependence, thus improving security of supply.

This article investigates the perspectives of renewable electricity generation in the South Caucasus region. Therefore, first the availability of RES is evaluated. Secondly, the economic feasibility is explored, using the levelised cost of electricity as a metric. The conclusion describes the additional benefits of RES.

Availability of Renewable Energy Sources

The overall potential of renewable electricity generation is usually classified in terms of theoretical, technical and economic potentials (Hoogwijk 2004):

theoretical potential > technical potential > economic potential

While the theoretical potential is an estimate of the total annual amount of a primary energy resource that is available in nature, the technical potential is defined as the usable portion if constraints like available and suitable terrain are considered and conversion losses are taken into account. The economic potential is the annual amount of electricity that can be obtained at cost levels that are competitive with alternative sources of electricity, considering current or projected technology costs and market conditions.

Especially for technologies other than hydropower, reliable data on the technical and economic potential of renewable electricity generation in the countries of the South Caucasus are still rare. Due to the limited availability of reliable data, we focus on solar photovoltaics (PV), as well as onshore and offshore wind power. A few estimations exist for the economic potential of onshore wind power in the region. According to USAID (2010), the potential in Armenia amounts to 1.6 TWh (terawatt hours) annually (about 22 percent of total electricity production in 2011), while Walden *et al.* (2013) estimate a potential of 2.4 TWh annually for Azerbaijan (about 12 percent of total electricity production in 2011). For Georgia, a technical potential of 5.0 TWh annually from onshore wind (about 49 percent of total electricity production in 2011) is given by USAID (2008). With regard to solar PV, reliable data could only be retrieved for Armenia, where a technical potential of up to 3.9 TWh (about 53 percent of total electricity production in 2011) is estimated (R2E2 Fund 2013). Data from this small number of studies can only be taken as a preliminary indicator of available RES potential in the South Caucasus region.

Based on weather data for the period 2000–2012, Janker (2014) compiled a global database of time series of potential electricity generation from wind and solar PV. From these time series annual full load hours (FLH) are derived, which indicate the amount of electricity that is generated per unit of installed capacity. Janker (2014) uses two different approaches to determine aggregate FLH for regions or countries: It is assumed that either installed capacity is uniformly distributed across the whole country or installed capacity is uniformly distributed only across the 33 percent of sites with the best conditions. While the assumption of a uniform distribution across the whole country might become more realistic with increasing shares of wind and solar power, it certainly does not hold for countries which are only starting to develop renewable electricity generation. Thus, FLH which are only based on the best 33 percent of sites are probably more suitable for the South Caucasus region. We examined average FLH of the period 2000–2012 in order to obtain a more representative estimate for each country (Table 1).

For onshore wind power, Azerbaijan offers the highest FLH value among the three countries of the South Caucasus. With an average of 1,041 FLH considering the best 33 percent of sites, conditions are, however, not as favourable as in Germany or the United Kingdom. The number of FLH that could be achieved for onshore wind in Armenia and Georgia is significantly lower. Offshore wind resources could possibly also be harnessed along the coasts of the Black Sea and the Caspian Sea. Whereas only a very low number of FLH can be expected along Georgia's Black Sea coast, the Caspian Sea offers significantly better conditions for electricity generation from offshore wind parks. With an average of 2,149 FLH for the best 33 percent of offshore wind sites, conditions on the Caspian Sea are still less attractive than in the North Sea region, where 3,693 FLH and 4,241 FLH are reached on average in the offshore zones of Germany and the United Kingdom respectively (Janker 2014). However, it should be noted that Kerimov *et al.* (2013) found capacity factors of 0.41–0.49 (i.e. 3,590–4,290 FLH) for offshore sites near Azerbaijan's Apsheron Peninsula.

The conditions for electricity generation from solar PV are favourable throughout the South Caucasus region, with achievable FLH in Azerbaijan and Armenia being slightly higher than in Georgia. Solar radiation however falls short of Mediterranean countries like Italy and Spain, where, according to Janker (2014), more than 1,350 FLH are reached on average (considering the best 33 percent of sites). Although this comparison of FLH indicates the limited performance of wind and solar power in the South Caucasus region, meaningful conclusions can only be drawn from an economic analysis.

Economic Feasibility of Wind Power and Solar Photovoltaics

The economic feasibility of renewable electricity generation in the South Caucasus is analysed by determining the levelised cost of electricity (LCOE) per technology and country. According to Kost *et al.* (2013), the LCOE of any power plant are the average costs per generated kilowatt hour of electricity, i. e. the present value of all costs associated with construction and operation divided by the amount of electricity generated over the whole life time of the plant. If costs and energy are scaled to installed capacity, the LCOE can be calculated by using FLH as a representation of annual electricity generation.

In order to calculate the LCOE of onshore wind, offshore wind and solar PV in the countries of the South Caucasus, it is assumed that the average FLH considering the best 33 percent of sites can be achieved. Due to the limited availability of data, investment costs as well as operation and maintenance costs (O&M) are based on values for Russia (Birol *et al.* 2014). The life time of wind turbines is assumed to be 20 years, while the lifetime of PV panels is assumed to be 25 years (Kost *et al.* 2013). Ondraczek *et al.* (2013) report current values of weighted-average cost of capital (WACC) for Armenia (15.2 percent), Azerbaijan (15.3 percent) and Georgia (17.8 percent), which are used as estimates of the interest rate in these countries. It should be noted that, compared to European countries, like France or the United Kingdom, for which 6.3 percent and 4.1 percent are reported, the cost of capital is relatively high in the South Caucasus countries.

The LCOE are determined for 2012 and 2020 (Figure 1). The 2012 level of investment and O&M costs as well as the current high level of WACC are used to assess the economic feasibility under current conditions. Moreover, the LCOE are also calculated based on the projected level of investment and O&M costs in 2020 and assuming a potential decrease of WACC from the current high level to 9 percent.

Generally, the LCOE of wind and solar power in the South Caucasus region are relatively high if current levels of costs and WACC are considered. In all three countries, onshore wind offers lower LCOE than offshore wind or solar PV under current conditions. Onshore wind in Azerbaijan represents by far the cheapest option to generate electricity in the region today. However, given the expected reduction of investment and O&M costs in the future, solar PV could become more attractive than onshore wind in Armenia and Georgia. The assumed reduction of cost of capital could further increase the competitiveness of solar PV in the region, compared to onshore wind in Azerbaijan.

In order to assess the economic feasibility of renewable electricity generation, the LCOE are compared with consumer electricity prices in this article. Thus, additional taxes or subsidies are not accounted for. With consumer electricity prices of 0.12–0.14 GEL per kilowatt hour (kWh) in Georgia (GNERC 2008), 26 AMD/kWh in Armenia (Kochnakyan *et al.* 2013) and 0.06 AZN/kWh in Azerbaijan (Kostopoulos *et al.* 2009), the current price level in the region amounts to approximately 0.05–0.06 €/kWh. In view of a minimum LCOE of 0.22 €/kWh, electricity generation from wind and solar power is thus not competitive under current conditions. While, on the one hand, investment costs are still too high, it also has to be noted that currently electricity prices in the region are not fully cost recovering (Vetlesen *et al.* 2012, Kochnakyan *et al.* 2013, Kostopoulos *et al.* 2009). Given the projected development of investment costs and cost of capital, the attractiveness of wind and solar power could improve significantly, reaching a minimum LCOE of 0.15 €/kWh. However, in order to become competitive, either electricity prices have to increase or support mechanisms have to be implemented. Although intended to promote the development of wind power, currently implemented feed-in tariffs of 33 AMD/kWh in Armenia (Danish Energy Management 2011) and 0.05 AZN/kWh in Azerbaijan (Moffatt *et al.* 2010) are not sufficient to stimulate investment.

Further Benefits of Renewable Electricity Generation

Despite the questionable economic feasibility, an early introduction of non-hydro RES in the electricity supply might still hold benefits for the South Caucasus countries. Whereas for Armenia renewable electricity generation opens up the possibility of reducing its dependency on energy imports, Azerbaijan should begin to gradually diversify its electricity generation to ensure security of supply and a sustainable economic development in the future. Another incentive to expand the utilisation of RES is the possibility to export electricity to neighbouring countries. With its growing electricity demand and a higher price level, Turkey could become a key market for renewable electricity from the South Caucasus (Ghvinadze & Linderman 2013). Furthermore, the seasonal characteristics of electricity generation from wind power could provide added value to the power system. As Kelbakiani & Pignatti (2013) point out, the seasonality of renewable electricity generation already has become a problem in Georgia, where hydro generation usually exceeds electricity consumption in spring and summer months, while, due to water shortages, hydropower is unable to meet demand in winter. Instead of further increasing hydropower capacity in Georgia, Kelbakiani & Pignatti (2013) suggest the complementary expansion of wind power, which exhibits seasonal characteristics similar to electricity consumption, i. e. a peak production in winter.

Conclusions

Based on the analysis of FLH, there should be notable potential for the development of onshore wind power, especially in Azerbaijan, for offshore wind power in Azerbaijan and for solar PV throughout the South Caucasus region. Although the literature generally supports these findings, there is still a strong need for further analysis of the technical and economic potential of wind and solar power.

The analysis of LCOE has demonstrated that, under current conditions, electricity generation from wind and solar power is not economically feasible in any of the countries investigated. As shown, expected investment cost reductions and the lower cost of capital could improve the overall attractiveness of RES significantly until 2020. If wind and solar power are, however, supposed to contribute to the region's electricity supply in the future, support schemes like feed-in tariffs or investment incentives have to be implemented.

In the long run, the expansion of RES might still hold benefits for the South Caucasus countries. Once the deployment of renewables has reached a certain level, both technical and financial incentives will call for the regional balancing of electricity generation. Therefore, wind, solar PV and hydropower could one day boost multilateral cooperation in the South Caucasus region.

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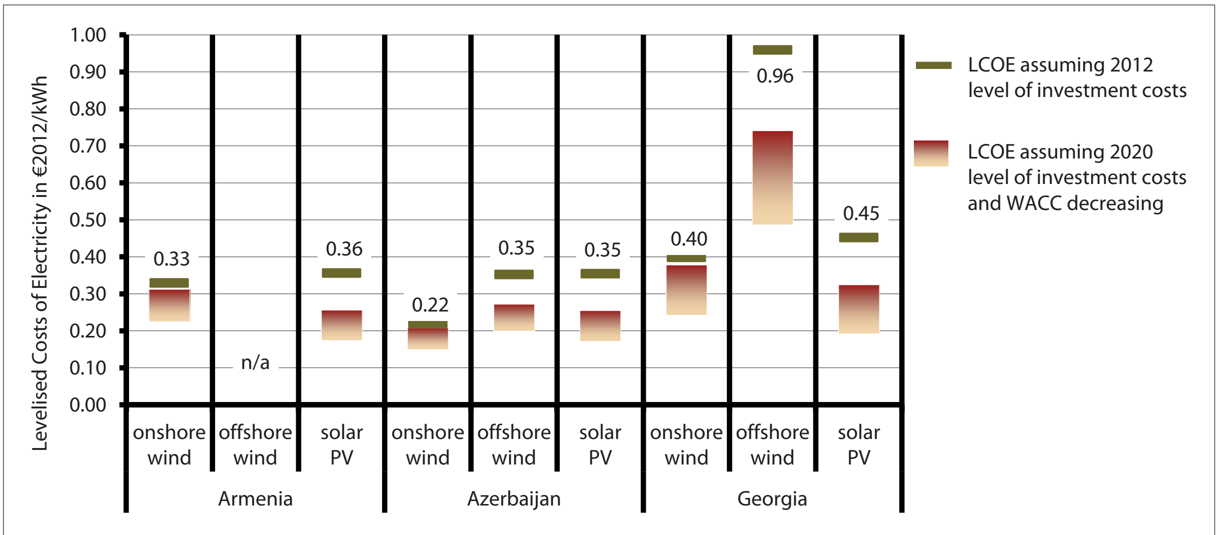
Table 1: Annual Full Load Hours of Electricity Generation from Wind and Solar Power (average for the period 2000–2012)

		Armenia in h/a	Azerbaijan in h/a	Georgia in h/a
onshore wind	all wind sites	510	581	307
	best 33 %	691	1,041	643
offshore wind	all wind sites	n/a	1,675*	635
	best 33 %	n/a	2,149*	880
solar PV	all PV sites	1,100	1,167	1,003
	best 33 %	1,165	1,178	1,053

** Full load hours of offshore wind are based on the whole area of the Caspian Sea.*
Source: Janker (2014).

Figure 1: Levelised Costs of Electricity in the South Caucasus Region



Source: Maximilian Kühne, Philipp Ahlhaus and Thomas Hamacher; NB: full load hours are based on best 33% of sites (Janker 2014); investment costs are based on investment costs for Russia in Birol et al.(2014); and current values of WACC for Armenia (15.2%), Azerbaijan (15.3%) and Georgia (17.8%) are based on Ondraczek et al. (2013).