The Eurasian Lignite Backbone

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Lignite, a low-grade fossil fuel in geological transition from peat to hard coal, is a mainstay of power generation and heating services between Central Europe and the Mediterranean Sea. Germany is the world's largest lignite producer with an annual output of 178 metric tons (Mt) in 2015, covering nearly a quarter of electricity demand. Although mining declined significantly after 1990 in the former East Germany and in Czechoslovakia, most other countries have increased usage. Foremost is Turkey, with lignite power generation expected to increase by over 80% within three years.

BROAD LIGNITE AVAILABILITY

Lignite deposits between Germany and southeastern Europe[1] constitute 45% of the EU's domestic energy reserves.[2] Mined lignite exhibits an energy content (heating value) considerably below that of wood pellets (17 MJ/kg) due to high water permeation and non-combustible ash and sulfur. The shallow deposits nevertheless permit surface extraction at a lower final energy cost than imported gas and coal.

At highly efficient power stations connected by conveyer belt to adjacent mines, Germany has achieved fuel expenses below 15 € per MWh of electricity.[3] Even when transported to distant plants by rail,[4] lignite remains less costly than natural gas generation approaching 100 €/MWh.

Lignite grid power costs vary significantly in the EU and Turkey due to differences in mining operations and thermal quality. The particularly low energy content of local deposits in Greece (3.8–9.6 MJ/kg at EURACOAL country profiles) makes lignite-fired electricity generation the most expensive at 59.9 €/MWh.[5] Romania achieves 54.2 €/MWh, followed by 53.6 in Germany, 52.7 in Turkey, 40.3 in Serbia, 39.0 in the Czech Republic, 38.6 in Poland, and 31.6 in Bulgaria.

Belchatow coal fired power station

"Lignite deposits between Germany and southeastern Europe constitute 45% of the EU's domestic energy reserves."

HISTORICAL GERMAN DOMINANCE

Before 1990, East Germany (the German Democratic Republic) was the world's largest lignite producer with over 300 Mt per year (18 t per capita) mined in Lusatia (near the Polish border) and in Central Germany. About 50 Mt/a of low-moisture briquettes were pressed from crude lignite for domestic and industrial heating.

Natural gas has since replaced briquette firing. Four central power stations as well as municipal CHP plants and sugar producers remain, together with the 900-MW Schkopau industrial plant that supplies grid electricity, 16-2/3 Hz railway power, and process heat for organic chemical manufacturing.

Eastern German mining output has dropped to a quarter of former levels, while annual production in the western German Rhineland has fallen less—from around 120 Mt to 95 Mt—due to plant retirements and efficiency measures.[6]

EUROPEAN LIGNITE TRANSITIONS

A comparison of mining figures from the 1970s with current statistics shows that lignite dependency has declined in only three economies: Germany, the former Czechoslovakia (now Slovakia and the Czech Republic), and Hungary (see Figure 1). Lignite usage in Slovakia has fallen to 2.2 Mt/a, or less than 0.5 t/a per capita.

Lignite mining has otherwise increased significantly. In 2014, the countries that previously comprised Yugoslavia produced a combined 51.1 Mt, compared with 31.7 Mt at the end of

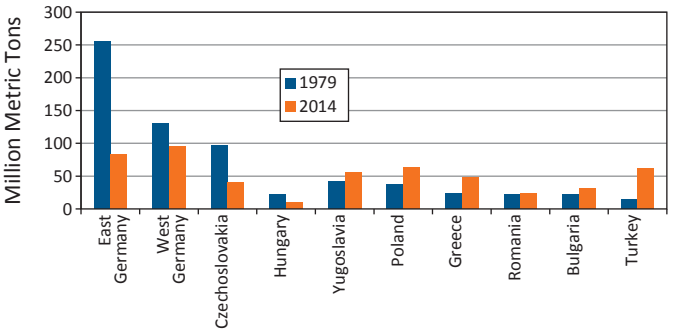

FIGURE 1. Annual lignite production 1979 and 2014

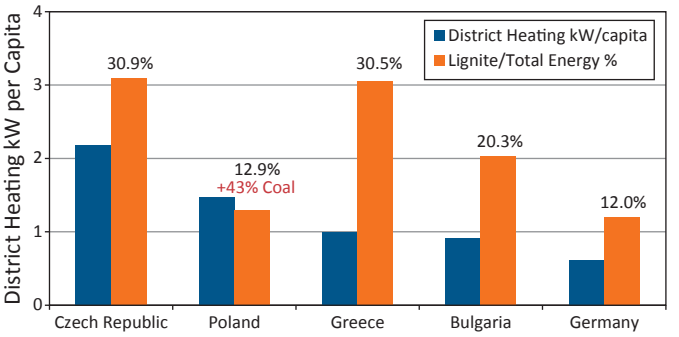

FIGURE 3: Ranking of district heating to lignite usage

the 1970s. Both Greece (48 Mt) and Poland (63.9 Mt) doubled annual tonnage, while lignite usage in Turkey more than quadrupled to 61.5 Mt in the same period.

Lignite reliance is increased by auxiliary energy services (see Figure 2). For instance, total primary energy consumption in the Czech and German economies approaches six metric tons of coal equivalent per inhabitant. However, lignite is responsible for over 30% of overall energy demand in the Czech Republic due to greater heating utilization.

As indicated in the ranking diagram of Figure 3, district heating[7] invariably incurs a higher level of dedicated fuel usage. In the case of Poland, heating demand is only partially covered by lignite due to the threefold reliance on hard coal that satisfies 43% vs. 12.9% of total energy requirements.

CLIMATE POLICY IMPLICATIONS

Burning a ton of mined lignite emits about a ton of CO_2. At below 900 Mt/a, however, global lignite combustion equates to less than 3% of accountable CO_2 emissions that totaled 35.7 Gt in 2015. Lignite provides particular logistical and geological benefits compared with other energy sources. Locating large power plants adjacent to mines precludes transport energy

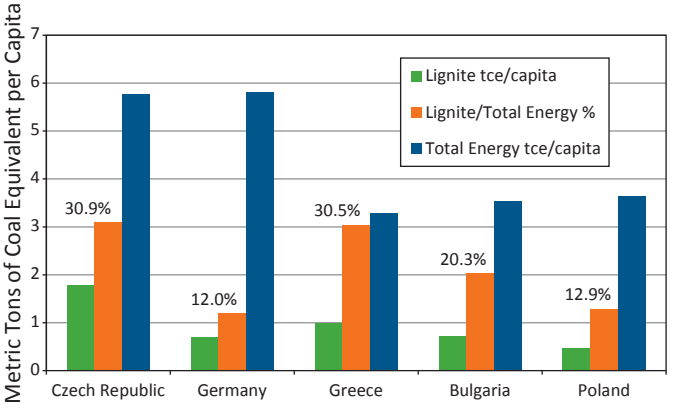

FIGURE 2. Ratio of lignite to total energy demand

losses. Combined heat and power generation increases net fuel utilization. Unlike gas and hard coal, lignite deposits release only negligible methane effluents. Biomass combustion, on the other hand, contributes significantly to climate change due to CO_2 emissions persisting in the atmosphere.

Following nuclear phase-out legislation enacted in 2011, Germany has been deviating from its 2020 greenhouse gas reduction target of 40% referred to 1990 (see Figure 4). Emissions of 908 Mt in 2015 would need to be reduced by another 159 Mt to meet this obligation, roughly equivalent to all lignite emissions in the electricity sector.

The Central German lignite miner MIBRAG (Mitteldeutsche Braunkohlengesellschaft mbH) estimates that switching to gas generation under the EU Emissions Trading Scheme (ETS) would entail a 10-fold price increase, resulting in a doubling of electricity rates.[8] In contrast with imported fuels, domestic lignite enables calculated costs to be maintained while providing the revenue streams required for post-mining landscape reclamation.

RELATIVE LIGNITE USAGE

Certain countries in the eastern Mediterranean region consume over four tons of lignite per capita annually (see Figure 5). The lower heating value of southern European lignite requires greater quantities of lignite to be burned.

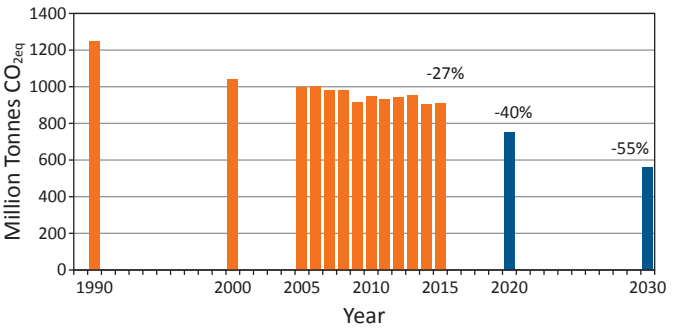

FIGURE 4. Greenhouse gas emissions and targets in Germany

The Czech Republic, however, uses the most lignite energy per inhabitant. Tonnage is comparable to that of Balkan countries, but heating values are in the range of 10.9–18.2 MJ/kg under current contracts. Prehistoric volcanic activity has resulted in both high carbon density and the imbued sulfur formerly responsible for forest mortality (*Waldsterben*) in the absence of SO_2 emission filters. Central German deposits north of the intervening Ore Mountains exhibit similar geological characteristics.

GERMAN LIGNITE SUSTAINS NUCLEAR PHASE-OUT

Lignite with thermal grades between 7.8 and 11.3 MJ/kg is used in Germany to generate nearly a quarter of the country's electricity (155 TWh/a in 2015). Together with heating services, lignite covers 12% of overall energy demand. Renewable power provides the same amount of primary energy. However, it is dedicated chiefly to supplanting Germany's remaining eight nuclear reactors that are being phased out by 2022 in compliance with the 2013 federal coalition agreement.

Nuclear generation accounts for 7% of primary energy and 14% of grid electricity. Renewable power exceeding 30% (196 TWh) must attain a commensurately higher post-nuclear level before lignite generation could be appreciably diminished. Due to ongoing delays in transmission line construction from offshore wind farms, that objective is unlikely to be achieved for another decade.

Licensed lignite reserves in the lower Rhine valley (currently 95 Mt/a) were recently reduced by 400 Mt in the RWE Garzweiler II mine, but without revising the final 2045 production date. A proposed power plant in Central Germany, a flexible 660-MW two-turbine design, was canceled by MIBRAG in April 2014. The corporation's Czech owner, Energetický a Prumyslový Holding (EPH), together with PPF Investments has instead

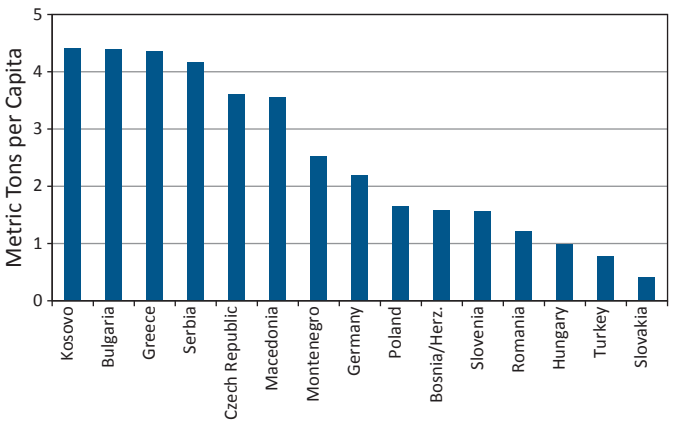

FIGURE 5. Lignite production per capita 2014

bought all four Vattenfall lignite mines and three power stations in Lusatia plus one Central German 934-MW block at Lippendorf. The combined capacity of approximately 8.1 GW includes the 2575-MW Boxberg site with a variable-fired 310–675-MW generator dedicated in 2012.

Two nearby Lusatian 500-MW units (of six blocks total) at Jänschwalde are being relegated to reserve status in 2018–2019 under a federal subsidy agreement. The MIBRAG 392-MW Buschhaus plant in Lower Saxony and five older RWE blocks in the Rhineland are also included in the staged retirement program, comprising 2.7 GW of overall capacity, which is intended to avoid 12.5 Mt CO_2 annually.[9]

The recent reorganization of RWE and EPH will enable the German lignite industry to maintain high grid dependability standards as nuclear power is superseded by renewable energies.

MINING EXPANSION IN POLAND

Domestic lignite and hard coal currently meet 56% of energy demand in Poland and account for nearly 90% of electrical power generation. Although particular coal operations are being terminated, lignite deposits extending below the Neisse River from Germany will enable new plant capacities to be added. A 100-km^2 surface mining site is undergoing preliminary licensing at Gubin-Brody to produce 17 Mt of lignite annually over 49 years from seams 140 m deep. PGE Polska Grupa Energetyczna intends to erect three 830-MW generation blocks for operation beginning in 2030.[10]

In southwest Poland at Turów, PGE began construction of a 450-MW lignite plant[11] in May 2015 to complement the existing six 250-MW turbines at this location. The close proximity of Germany and the Czech Republic could promote the international development of reduced-emissions lignite technologies.

Europe's largest lignite power station at Bełchatów with 5354-MW generation capacity has been modernized for extended operation. All major lignite sites are prepared for CCS retrofits if warranted by EU decarbonization strategies, with CO_2 storage proposed under the Baltic Sea.

MINING LIMITS LIFTED IN THE CZECH REPUBLIC

Since the 1990s, the Czech semi-state energy corporation ČEZ has upgraded its power plant fleet, beginning with the desulfurization of 6462 MW of installed lignite capacity.[12] The Tušimice II (4 ×200 MW) and Prunéřov II (5 × 210 MW) power stations have been completely refurbished for generation until at least 2040. Restrictions imposed in 1991 by Parliamentary Resolution 444 for Northern Bohemian lignite mining have been successively lifted.

Mining operations are being prolonged from 2036 to 2049 at Bílina to supply an additional 100 Mt of lignite to the newly constructed Ledvice 660-MW plant. The single-generator design expands the existing 330 MW of electrical capacity, providing heat to 300 commercial customers and 20,000 private households.

During 2014–2015, over 1 Mt/a of Central German lignite was shipped by rail from MIBRAG mines to the Opatovice and Most-Komořany power plants, which are likewise owned by EPH. While these imports have since been discontinued, briquettes manufactured by MIBRAG with low-sulfur RWE lignite continue to be delivered to the Czech domestic heating market.

Ongoing lignite dependency is sustained by district heating services. Nuclear generation capacities may be expanded in future decades at Dukovany and Temelin.

BULGARIA: LIGNITE ECONOMIC STABILITY

Over 95% of Bulgarian lignite is mined in the Maritsa East (Iztok) Basin. The 240-square-mile expanse is the largest mining site in southeastern Europe, making its operator, Mini Maritsa-Iztok EAD, the most important employer in Bulgaria. The local lignite exhibits a 16–45% proportion of ash with heating values ranging from 6.5 MJ/kg for steam grades to 7.3 MJ/kg for briquette manufacturing.[13] The 1.95–2.4% sulfur content is higher than in northern European deposits.

In addition to two successively modernized power stations with 2365 MW, the AES Bulgaria 600-MW Galabovo plant completed in 2011 constitutes about 5% of the country's installed power capacity. The € 1.3 billion installation uses approximately a quarter of the lignite mined at this location (5 Mt/a).

ROMANIAN ENERGY DIVERSITY

Romanian lignite with 7.2–8.2 MJ/kg has a comparatively low moisture content of 41–43%. Lignite accounts for nearly one-fourth of primary energy consumption and about half of electricity generation,[14] with demand at around 30 Mt/a. However, oil, gas, and coal contribute to broad domestic supply diversity. Romania also has the highest installed wind power capacity in southeastern Europe with over 3.1 GW.

SECONDARY LIGNITE ROLE IN HUNGARY

The Visonta and Bükkábrány surface mines operated by Mátrai Erőmű ZRT northeast of Budapest provide about 90% of Hungarian lignite. The overburden-to-lignite ratio of 9:1 indicates high expenditures for earth-moving. Lignite is used to supplement the country's natural gas resources. The Mátra Visonta power station comprises five lignite-fired boilers with

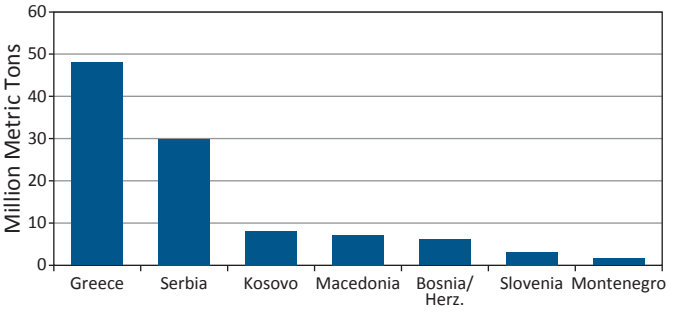

FIGURE 6: Greek and Balkan lignite production 2014

876-MW total generation along with two gas turbines of 2 ×30 MW. Biomass is also co-fired up to 10%. Lignite in combination with non-fossil generation therefore serves to cushion the power market against price volatility.

GREECE AND THE FORMER YUGOSLAVIA

Lignite significantly contributes to domestic energy security in Greece and the former Yugoslav states (see Figure 6). Mining has been terminated in Croatia, but the remaining Balkan countries are using their lignite resources. The thermal qualities available in Slovenia (11.3 MJ/kg) and Serbia (7.8–8.2 MJ/kg) are comparable with northern European grades. Lignite provides half of Serbia's total primary energy (see Figure 7).

New power plants in the region are dependent on external financing, such as the 660-MW Ptolemaida V expansion in Greece co-funded by the KfW German Development Bank. Although the underlying decisions have been criticized by environmental organizations such as the WWF,[15] economic stabilization takes priority over climate policies. Plant expansions await approval at Kolubaru (2 × 375 MW) in Serbia and near Přistina (2 × 300 MW) in Kosovo, where Europe's fourth-largest lignite resources (after Poland, Germany, and Serbia) are located.[16] Future generation may be developed with greater reliance on renewable energies.

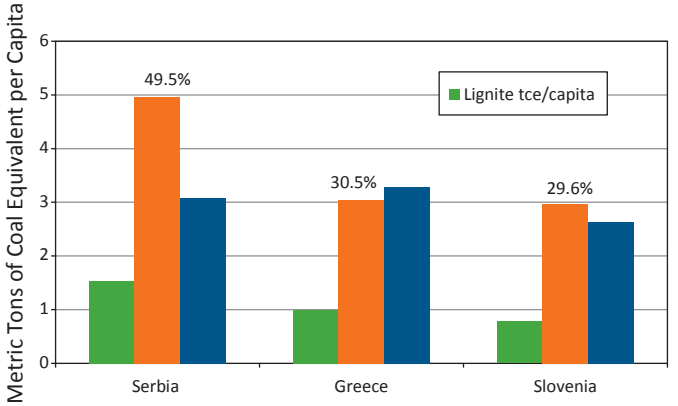

FIGURE 7: Ratio of Balkan lignite to total energy demand

LIGNITE EXPANSION PLANS IN TURKEY

In 2015, Turkey met 12% of overall electricity demand with lignite plant capacity of 8.1 GW.[17] According to research by the Institute for Energy Economics and Financial Analysis, the most recent energy legislation will raise lignite power generation from 31.2 TWh in 2015 to 57 TWh by 2018. Newly constructed plants would receive guaranteed revenues of 8 cents per kWh, necessitating a 3.5 cent subsidy at current power trading prices.

Tentative Chinese financing of US$10–12 billion was announced in 2014 to expand the existing 2795-MW AfSin-Elbistan generation site to 8 GW.[18] Overall, more than 80 coal and lignite plants have been variously listed in planning and construction.

Despite the carbon footprint inherent to increased fossil fuel usage, Turkey's Intended Nationally Determined Contribution (INDC) statement, submitted on 30 September 2015 for climate negotiations in Paris, has established that greenhouse gas emissions could be reduced by up to 21% below business as usual (BAU) in 2030 by including land use, land use change, and forestry (LULUCF).[19] Comprehensive mitigation plans are intended to abate up to 255 $MtCO_2e$ by that time over BAU.

DURABLE PROSPECTS FOR LIGNITE USAGE

Lignite remains a reliably calculable domestic energy resource in most countries between Germany and Turkey. Heating services in combination with power generation provide highest fuel utilization. The retirement of aging power plants additionally contributes to fulfilling CO_2 reduction obligations.

The increasing deployment of renewable power technologies challenges the competitive advantage of conventional fuels in electricity generation. Established district heating networks, however, depend widely on low-cost lignite extracted as needed from surface mines. There are no comparable biomass resources in Europe.

Significantly, Turkey is expanding lignite utilization despite having twice the solar irradiation of Germany, where 16% of worldwide photovoltaic capacity is currently installed. Since renewable energy deployment entails particularly high technology outlays, adequate infrastructure prerequisites have yet to be established in the Mediterranean region.

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