Global opportunities and challenges for coal combustion products with a Circular Economy

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ABSTRACT

Reported in 2019 coal and its use in energy production is under considerable scrutiny using current combustion technology and resulting CO_2 emissions with the main driver being climate change. Over the past two years numerous countries have accelerated the pace of planned closures of coal fired power facilities, especially in Europe. New technologies such as High Efficiency Low Emissions (HELE) afford significant emission reductions, but the energy policy uncertainty across the globe continue to retard investment. Coal use and accordingly coal combustion products has continued to grow in South-East Asia and India and to stabilize or slightly reduce in China, Japan and Korea and to be further reduced in America, Europe and Australia.

Coal combustion products (CCPs) are well established as valuable, high-volume inputs for the manufacture of construction and building materials. Functional benefits result in applications such as substitutes for energy and resource intensive materials including cement, sand and aggregates – these not only provide options for lower embedded carbon but contribute towards the principles of circularity of products and constructions where they are used.

The circular economy is a modern term used to describe an alternative to a traditional linear economy (manufacture, use, dispose). In a circular economy we keep resources in use for as long as possible, thus extracting the maximum value from them whilst in use, then recover and regenerate products and materials until the end of each service life. This adds to the raw material efficiency of products where CCPs are considered valuable raw materials.

Challenges discussed in this paper include addressing future resources demands through increased production of certified sources, harvesting of surplus CCPs, navigating diverse regulatory constraints and managing risks – importantly – increasing general consensus within regional and international product standards and improving supply-side (Generators of CCPs) knowledge of quality consistency by consumers.

INTRODUCTION

Over the last years a drop in total coal demand is observed which is partly due to climate change but also due to lower energy demand, lower gas prices and increased production by renewables. This drop is not equal in all countries. Some countries have accelerated the pace of planned closures of coal fired power facilities, especially in Europe where climate neutrality is aimed by 2050. Other countries consider High Efficiency Low Emissions (HELE) technologies for emission reductions while increasing capacities for serving future energy demand. For this coal use has continued to grow especially in South-East Asia and India and to stabilize or slightly reduce in China, Japan and Korea and to be further reduced in America, Europe and Australia.

Linked with the energy production of coal is the production of Coal Combustion Products- (CCPs) which are partly used since decades as construction raw materials in various applications considering their properties. CCP use results in savings of natural resources and energy demand for mining and processing. By this CCPs contribute to the sustainability of construction products and constructions and contributes actively to their circularity. Worth to mention that the increasing demand in developed markets due to raw materials scarcity and climate neutrality aims is facing availability problems where ashes from stock are re-used to serve market needs. On the other hand today surplus to need coal ashes are placed into long-term storage or disposed of due to off-specification qualities and non-developed markets.

The members of the World Wide Coal Combustion Products Network (WWCCPN) endeavor to continuously inform global stakeholders about developments in the production, utilization and trading of CCPs. The most recent data are provided with this paper.

ROLE OF COAL IN ENERGY PRODUCTION

After several years of constant increase the world total coal production reached a peak by 2015. In 2020, the coal production decreased by 4.8% after three years of growth (see figure 1). China was the only major producer that increased coal production in 2020. Further declines are observed in the United States and the European Union. Production growth in Russia, Indonesia, India and Turkey[1].

The BP statistics provides that energy consumption decreased by 4.5% last year, the first decline in energy consumption since 2009. The decline was driven largely by oil (-9.7%), which accounted for almost three quarters of the decrease. Consumption for all fuels decreased, apart from renewables (+9.7%) and hydro (+1.0%). Consumption fell across all the regions, with the largest declines in North America (-8.0%) and Europe (-7.8%). The lowest decrease was in Asia-Pacific (-1.6%) due to the growth in China (+2.1%), the only major country where energy consumption increased in 2020. In the other regions, the decline in consumption ranged between -7.8% in South and Central America to -3.1% in the Middle East (see figure 2)[2].

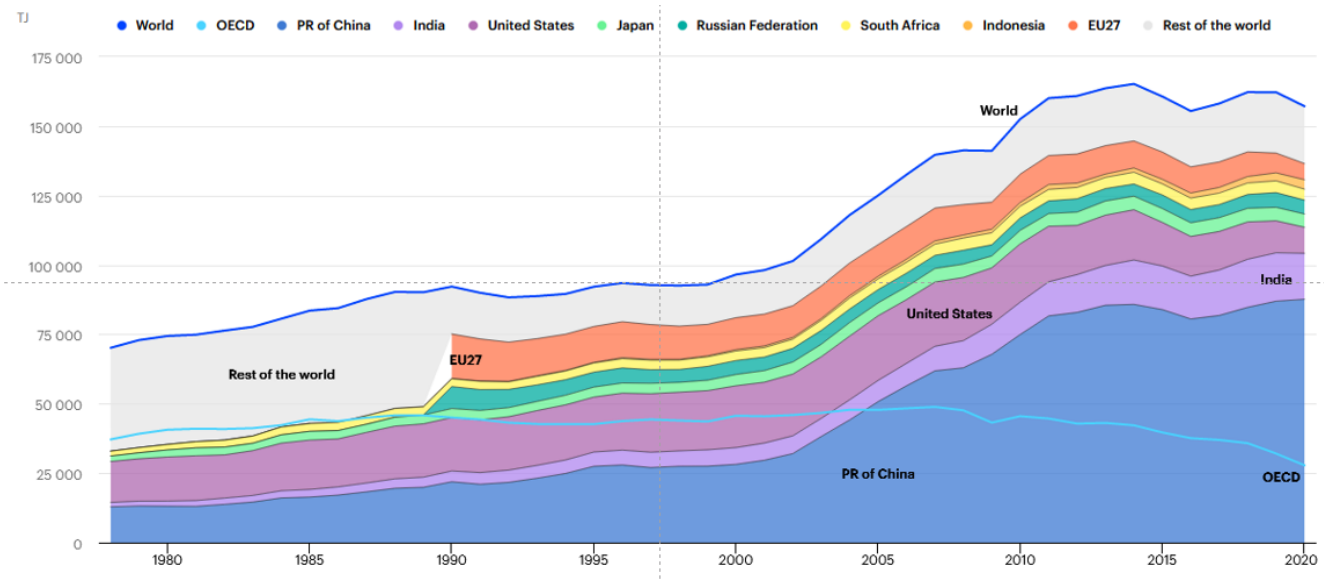

Figure 1 World total coal production[1]

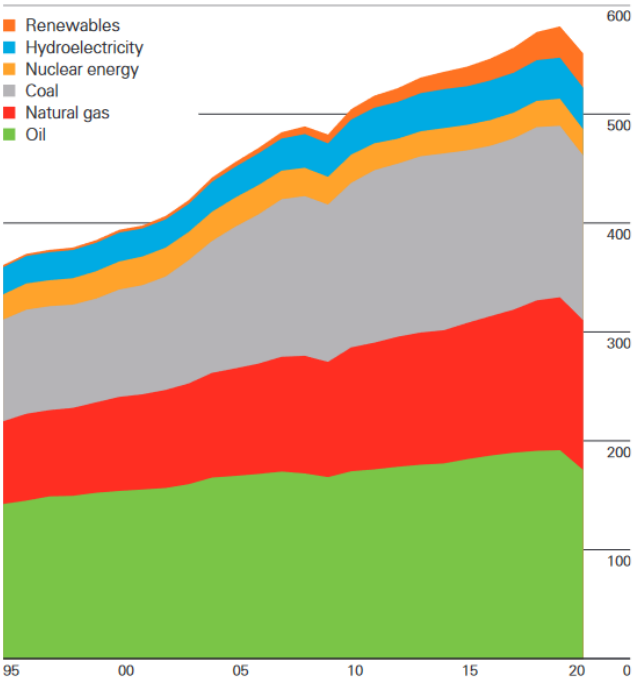

Figure 2 World energy consumption in [Exajoules][2]

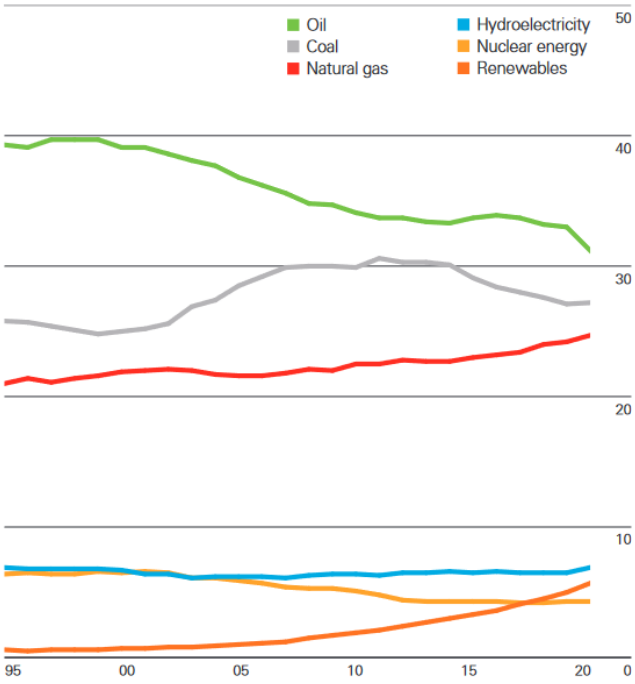

Figure 3: Share of global primary energy; in [percent][2]

Oil continues to hold the largest share of the energy mix (31.2%). Coal is the second largest fuel in 2020, accounting for 27.2% of total primary energy consumption, a slight increase from 27.1% in the previous year. The share of both natural gas and renewables rose to record highs of 24.7% and 5.7% respectively. Renewables has now

overtaken nuclear which makes up only 4.3% of the energy mix. Hydro's share of energy increased by 0.4 percentage points last year to 6.9%, the first increase since 2014[2].

The majority of coal is either utilised in power generation, using steam coal or lignite, or iron and steel production that uses coking coal. The share of coal in the world power mix is about one third but changes are only markable in specific regions. The increase in world electricity consumption is closely linked with economic growth, and economic growth in turn relies upon dependable sources of power. While coal power can, in several geographies, provide reliable supply, demands for climate change mitigation, transition to renewable energy forms and increased competition from other resources are presenting challenges for the sector.

Based on major agreements for protection environment and climate the coal-fired power production is under increasing pressure to become climate neutral. Over the past decades, national governments have required that coal combustion for energy production meet emissions standards for clean air. This has resulted in emission reduction technologies for dust, NOx and SOx and efforts to improve overall combustion efficiency. Along with these national regulations, global discussions on climate protection have led to international agreements with further regulations applying in signatory countries. The Climate Convention, Kyoto Protocol and Paris Agreement are all well-known initiatives which aim at reducing CO_2 emissions and mitigating risks of global warming.

MAJOR CLIMATE AGREEMENTS

- UNFCCC

The United Nations Framework Convention on Climate Change (UNFCCC) is the main international agreement on climate action. It was one of three conventions adopted at the Rio Earth Summit in 1992. Its sister Rio Conventions are the UN Convention on Biological Diversity and the Convention to Combat Desertification. The convention entered force on 21 March 1994. It started as a way for countries to work together to limit global temperature increases and climate change, and to cope with their impacts. The 197 countries that have ratified the Convention are called Parties to the Convention (CoP)[3]. THE COP26 from 31st October to 2th November 2021 summit in Glasgow/UK will accelerate actions towards the goals of the Paris Agreement and the UN Framework Convention on Climate Change[4].

- KYOTO PROTOCOL

When the UNFCCC realised that stronger provisions were needed to reduce emissions they agreed to the KYOTO PROTOCOL in 1997. The protocol introduced legally binding emission reduction targets for developed countries. The participating countries have pledged to reduce their emissions by an average of 18% (as against 1990 levels) over the period 2013-2020. Within this framework the European Union pledged to a reduction of an average of 20% which was increased later on to 40% and aims in climate neutrality by 2050[5].

The Protocol offers additional means to meet targets by way of three market-based mechanisms, such as International Emissions Trading Mechanism (ETM), Clean Development Mechanism (CDM) and Joint Implementation projects (JI). The *CDM,* for example, allows emission-reduction projects in developing countries to earn Certified Emission Reduction (CER) credits, each equivalent to one tonne of CO_2. Accepted CDM and JI projects are listed in the UNFCCC CDM data base[6]. One example of a JI project referring to the use of coal ash is the TEFRA project from Poland, involving three installations in different locations, where coal ash is used or planned to be used in the production of hydraulic binders[7].

- PARIS AGREEMENT

On 12th December 2015, parties to the Paris Climate Conference reached a new global agreement on climate change. Article 2 of the Paris Agreement defines the three purposes of the instrument:

- to make mitigation effective by holding the increase of temperature well below 2°C, pursuing efforts to keep warming at 1.5°C above pre-industrial levels;
- to make adaptation possible for all parties; and
- to make finance available to fund low carbon development and build resilience to climate impacts.

Noting the increasing number of natural disasters like floods, droughts and thunderstorms the number of countries announcing pledges to achieve net-zero emissions over the coming decades continues to grow. The International Energy Agency outlined that the pledges by governments to date – even if fully achieved – fall well short of what is required to bring global energy-related carbon dioxide emissions to net zero by 2050 and give the world an even chance of limiting the global temperature rise to 1.5 °C. In May 2021, they published a report “Net Zero by 2050 – A Roadmap for the Global Energy Sector” which provides ways for transition to a net zero energy system by 2050 while ensuring stable and affordable energy supplies, providing universal energy access, and enabling robust economic growth. It sets out a cost-effective and economically productive pathway, resulting in a clean, dynamic and resilient energy economy dominated by renewables like solar and wind instead of fossil fuels. The report also examines key uncertainties, such as the roles of bioenergy, carbon capture and behavioural changes in reaching net zero[8].

In the ASEAN Region, the regional forecast determined that existing national renewable policies and targets are insufficient to achieve the regional target by 2025. Grid reliability due to intermittency of Variable Renewable Energy (VRE) technologies such as solar and wind power remains to be a major challenge. Until the advanced grid integration technologies – such as storage, smart grids intelligence, and digital technology for demand management – reach technology saturation such that their price falls due to the economies-of-scale, coal and natural gas power will remain the main source to back up and maintain grid stability to ensure energy security.

The region employs High-Efficiency Low Emission (HELE) technologies such as Super Critical (SC) and Ultra-Super Critical (USC) Pulverise Coal Technologies for new coal-fired power installations. ASEAN also explores the feasibility of adopting technologies that can reduce emissions and improve existing coal-fired power plants such as coal upgrading, cofiring systems with biomass, Carbon Capture Utilisation and Storage (CCUS), and flexible operation for more sustainable coal use. ACER/JCOAL have prepared a report which recommends policy developments and updates on increased HELE utilisation, enhanced pollution, and emission regulation, and Carbon capture, utilisation, and storage (CCUS) deployment[9].

COAL COMBUSTION PRODUCTS – ROLES AND OPTIONS IN A CIRCULAR ECONOMY

The changing regulatory environments described above impact operating conditions for power plants which can lead to advers effects on quality, consistency and availability as the beneficial use of CCPs as raw materials in construction materials and constructions is well established. Globally, various terms have been used to describe CCPs. Terms including coal ash, pulverized fuel ash, coal utilisation by-products (CUBs), coal combustion by-products (CCBs), coal combustion resides (CCRs), coal combustion wastes (CWRs) and others are used to describe what are basically the same materials. Precise understanding and consistent definitions are important in drafting effective regulations and standards. In an attempt to facilitate precision and consistency the members of the World Wide Coal Combustion Products Network ('WWCCPN'[1] or 'Network') have collaborated to harmonize terminology and to promote CCPs as the consistent nomenclature. This terminology is a more positive view and is in keeping with the concept of industrial ecology and circular economy principles being an approach which seeks to reuse one industry's by-products as another industry's raw material. The WWCCPN global definitions for coal combustion products are given in table 1[10].

Building upon these consistent definitions, unambigious regulatory classifications can be developed which create important understanding about the positive experiences regarding utilization and transport. Table 2 gives an update on the classification status of CCPs in countries reported by the WWCCPN[11].

[1] http://www.wwccpn.org/ The WWCCPN is a coalition of international Associations interested in information exchange concerning management and use of CCPs.

The most recent change in classification was observed in Indonesia where the Indenesian Government has deregulated several industrial byproducts from the list of hazardous and toxic (B3) waste including fly ash and bottom ash from coal burning[12].

Table 1. WWCPN global definitions for coal combustion products[10]

Term	Definition
Coal Combustion Products	Coal combustion products (CCPs) include fly ash, bottom ash, boiler slag, fluidized-bed combustion (FBC) ash, or flue gas desulfurization (FGD) material produced primarily from the combustion of coal or the cleaning of the stack gases of coal fired power stations. The term coal ash is used interchangeable for the different ash types.
Fly ash	The finer ash produced in a coal fired power station, which is collected using electro-static precipitators. This is also known as Pulverised Fuel Ash (PFA) in some countries. About 85+% of the ash produced is fly ash.
Furnace Bottom Ash (FBA)	The coarse ash that falls to the bottom of a furnace. The molten ash adheres to the boiler tubes, eventually falling to the base of the furnace. ….. Usually <15% of the ash produced is FBA
Cenospheres	Hollow ash particles that form in the furnace gas stream. They float on water and are usually collected from lagoons, where ash/water disposal systems are being used.
Conditioned ash	Where fly ash is mixed with a proportion of water (10 to 20% by dry mass typically) in order that it can be transported in normal tipping vehicles without problems with dust for sale or disposal.
Flue Gas De-sulfurisation	Where a source of calcium is injected into the furnace gas stream to remove sulfur compounds. The sulfur compounds convert the calcium carbonate to calcium sulfate, or gypsum, which is used in the wallboard industry for general construction

Table 2. Environmental Classification Systems adopted by Country[11]

Countries	Defined as Waste	Defined as haz.waste	Basel Convetion adopted	REACH adopted	IInt'L Treaty on Mercury[3]	Utilis. Env. Condit.
United States	Yes	No	Yes	No	Yes	Yes
Australia	Yes	No	Yes	No	No[4]	Yes
Canada	Yes	No	Yes	Ref	Yes	Yes
China	Yes	No	Yes	Yes[2]	Yes	Yes
Europe	Yes[1]	No	Yes	Yes	Yes[4]	Yes
India	Yes	No	Yes	No	Yes	Yes
Indonesia	Yes	No	Yes	No	Yes	?
Israel	No	No	Yes	No	No	Yes
Japan	Yes	No	Yes	No	Yes	Yes
Russia	Yes	No	Yes	No	Yes[4]	Yes
South Africa	Yes	No	Yes	No	Yes[4]	Yes

[1] – in some member states defined as by-products or products
[2] – China REACH is similar to EU REACH
[3] – International Treaty on Hg, under UN Environment Program; [4] – partly not ratified yet

CCP PRODUCTION

The WWCCPN gather, collate and publish production and utilization data provided by members or from publically available and proven sources which summed up to approximately 780 Million metric tonnes (Mt) for 2010. Updates have been in 2013, 2015 and 2017 by Heidrich et al[13]. Harris et al reported in 2019 1.2 billion tonnes[14].

Table 3 reports on Annual Production, Utilization Rates by Country in 2019. The largest coal combustion product producing countries were China, India, Europe and the USA. Global production totaled nearly 1.1 billion tonnes for 2019 which is the same than the year before but considers less production in US and Europe and higher ones in China and India.

Table 3. 2019 Annual Production and Utilisation Rates of CCPs by Country[11]

Country/Region	CCPs Production (Mt)	CCPs Utilisation (Mt)	Utilisation Rate %
Australia	12.6	5.9	46.8
Asia			
- China	585	404	69.1
- Korea	7.5	6.2	82.7
-India	226	191	84.5
-Japan	12.3	12.1	96.9
- Other Asia	22.4	13.2	58.9
Europe	103		
-EU15	*19.4*	*21.5*	*110.8*
Middle East & Africa	33.9	3.9	11.5
Israel	0.6	0.5	83.3
United States of America	45.8	27.3	59.6
Brazil	4.1	1.2	30.0
Canada	3.2	3.0	93.8
Russian Federation	30.2	3.1	10.3
Total	**1086.6**	**692.1**	**63.9**

The utilization varies widely in the countries discussed in this paper depending on the type of coal and the combustion technology resulting in respective properties decisive for use. Utilisation rates range from about 10 % to 11 % for Russia and Africa/Middle East to more than 100 % in Europe resulting from harvesting CCPs from long-term storage. The countries with a high utilization rate also demonstrate an existing market where CCPs are used regularly according to existing regulations and can easily be put into the market. CCPs are mostly used in cement and concrete applications, especially those

with siliceous properties (or class F). Furthermore they are used in road construction, especially when stocks are available, and for filling applications.

Calcareous coal ashes are mostly used for reclamation or, due to their hydraulic properties, as binders. FGD gypsum is predominantly used as raw material for the gypsum industry in different applications including manufacture of wallboard and plaster, in the cement industry as a setting regulator as well as a fertilizer in agricultural applications. With their use CCPs replace natural materials and grant energy savings for their production. They also contribute to the sustainability of construction products and construction as climate neutrality has also to be considered by them.

SUMMARY/OUTLOOK

Coal still provides about one third for the world-wide energy production with declining forecast for climate protection aiming in phase-out or climate neutrality considering new technologies such as HELE for the interim operation of coal-fired production. The worldwide production of CCPs is greater than 1.1 billion tonnes with utilization rates from 10 to more than 100 %. For the utilization of CCPs legal and technical requirements have to be considered. The dislocation between markets and jurisdictions across the globe continues with some continuing to refer to CCPs either as waste or resources, by-products or products and used widely in construction applications.

Through the WWCCPN we continue to promote consistent terminology and classification of by-products from coal combustion as coal combustion ‘products’ (CCPs) – which contribute significantly as raw material in construction applications considering their properties. Furthermore, CCPs contribute to the circularity and finally also the sustainability of products and constructions. The members of the World Wide Coal Combustion Products Network will continue to promote, coordinate and inform the public, industry and governmental entities about the beneficial environmental, technical and commercial uses of Coal Combustion Products.

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