Abstract on the potential GHG emissions reduction in Turkey through the cement industry

Aug. 2018

1. EXECUTIVE SUMMARY

The cement industry emits in total **55.2 Mt of CO2 eq. in 2016** which results in the addition of the "combustion" and the "non-fuel combustion" GHG emissions from cement manufacturing. This is an **average of 813 kg of CO2 eq. per ton of clinker produced**. This represents **11% of the Turkish National GHG emissions in 2016**.

Four main levers can mitigate CO2 emissions from cement industry.

a) improving energy efficiency

b) reducing clinker content in cement

c) switching to fuels that are less carbon intensive (e.g. alternative fuels)

d) and implementing innovative technologies such as carbon capture.

Out of these levers reduction of clinker content in cement is by far the most effective. LC3 (www.LC3.ch), a new cement made of 50% clinker, 30% calcined clay, 15% limestone, and 5% gypsum, achieves same performances than CEM I. Replacing CEM I by LC3 could reduce total CO2 emissions from Turkish cement industry by 12.4 Mt (based on 2016 figures).

In addition, use of 40% alternative fuels in the fuel mix would further reduce CO2 emissions by 2.2 Mt, **thus reaching a total of 14.6 Mt for the Turkish cement industry. This represents a reduction of 26% as compared to 55.2 Mt CO2 emissions 2016.**

On September 30th, 2015, Turkey submitted its Intended Nationally Determined Contribution (INDC) to UNFCCC but curiously its mitigation scenario does not include any reduction in IPPU or non-fuel combustion CO2 emissions though it represents the largest % of CO2 emissions from clinker production. In this document we show how 10 million tons CO2 eq. emissions form "non-combustion" could be saved with the current cement production.

2. THE TURKISH GHG EMISSIONS

2.1 GHG emissions per details

Turkey's total GHG emissions, excluding the LULUCF (land use, land use change and forestry sector), were estimated to be **496.1 Mt of CO2 equivalent** (CO2 eq.) in 2016. This represents an increase of 135.4% above 1990 levels of 210.7 Mt Of CO2 eq. (Turkish Statistical Institute, 2018)

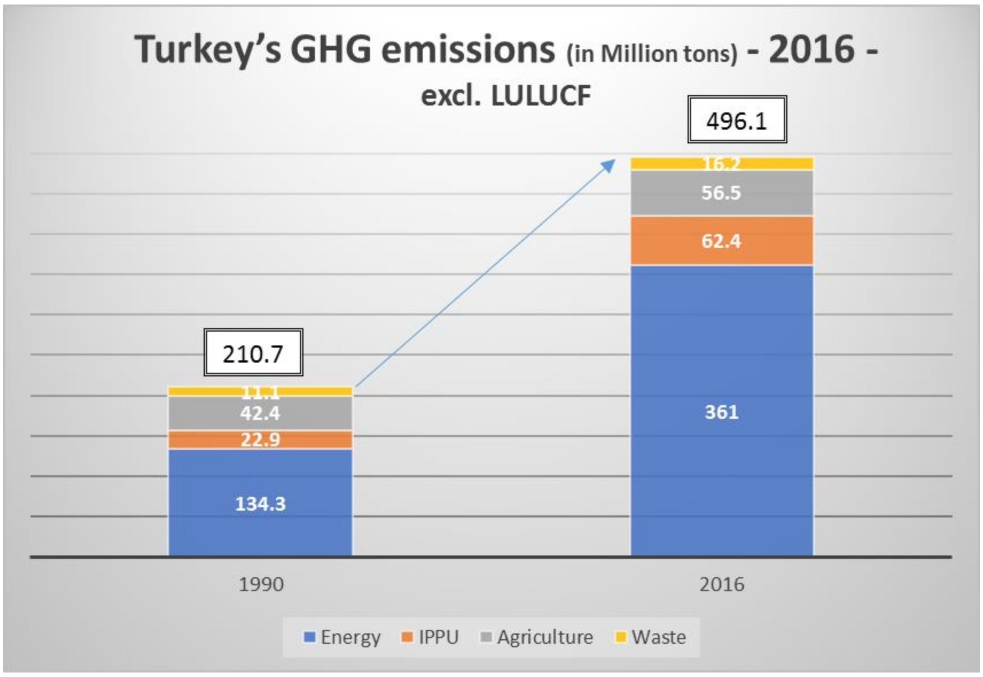

Figure 1: Greenhouse gas emissions evolution, 1990 & 2016 - Turkish Statistical Office

GHG emissions from energy increased 169% as compared to 1990. CO2 emissions from industrial processes increased 173% as compared to 1990.

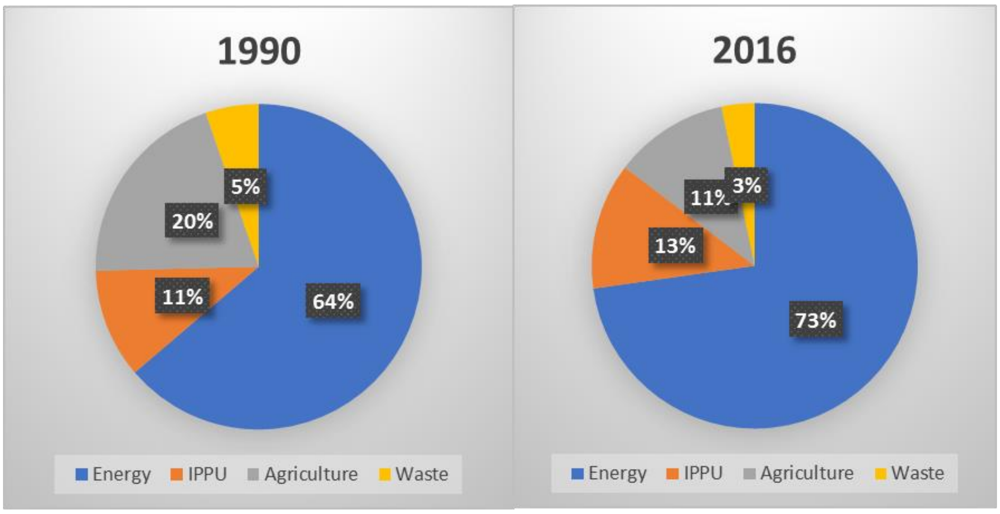

Figure 2: Greenhouse gas emissions by sectors, 1990 & 2016 – Turkish Statistical Office

With 73% of the emissions in 2016, the energy is Turkey's main source of GHG generated by the combustion of fuels for power and industrial production. Far behind in terms of GHG emitters are the sectors of IPPU (Industrial Process and Product Use) with 13%, the agriculture with 11%, and the waste with 3%.

2.2 The Energy sector or Fuel combustion GHG emissions:

The energy sector is Turkey's main source of GHG emissions and represents emissions from the combustion of fossil fuels (1.A.1 energy industries; 1.A.2 manufacturing industries and construction;

1.A.3 transport; and 1.A.4 other sectors; as well as fugitive emissions from fossil fuels (1.B) and CO2 transportation and storage (1.C)).

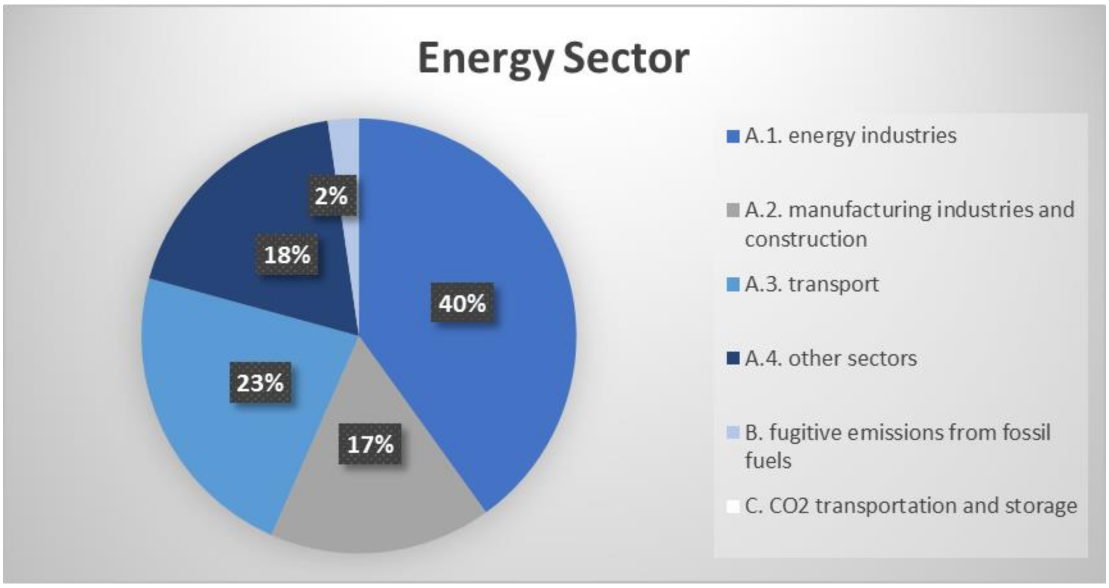

Figure 3: The detailed energy sector GHG emissions in % - Turkish Statistical Office

Emissions caused by the combustion of fuel in the manufacturing industry and construction" represents 17% of the total GHG emissions from the energy sector. This category consists of manufacturing industries sectors as iron and steel, nonferrous metal, chemicals, pulp, paper and print, food processing, beverages and tobacco, non-metallic minerals (including cement) and other industries.

2.3 The non-metallic minerals fuel combustion GHG emissions

The non-metallic minerals regroup GHG emissions from combustion of fuel from the cement manufacturing industry as well as Glass and ceramic production. This group represents 54% of the total emissions from manufacturing industries and construction with 32.3 Mt of CO2 eq. in 2016 while it was only 25.4% in 1990. This means that this sector contribution in the GHG more than doubled in 16 years. It is estimated that the cement industry itself represents **19 Mt of CO2 eq**. which represents 5.4% of the Energy sector and 4% of the national GHG emissions.

2.4 The IPPU sector or the Non-fuel combustion GHG emissions:

The GHG emissions from IPPU -industrial processes and product use- are released as a result of manufacturing processes. It means this category includes only emissions from processes and not from fuel combustion used to supply energy for carrying out the processes. For that reason, emissions from industrial processes are referred to as non-combustion.

For the year 2016, total GHG emissions resulting from the Industrial processes sector constitute 13% of total emissions with 62.4 Mt CO2-eq. Compared to 1990, (22.9 Mt CO2 eq.) an almost threefold increase in 16 years.

In 2016, 67% of GHG from industrial processes originated from the mineral products sector. So not only GHG from industrial process originated from the mineral sector represents the highest portion of the GHG emissions from the IPPU sector, but the mineral sector (including the cement industry) represents the highest emissions growth of the IPPU.

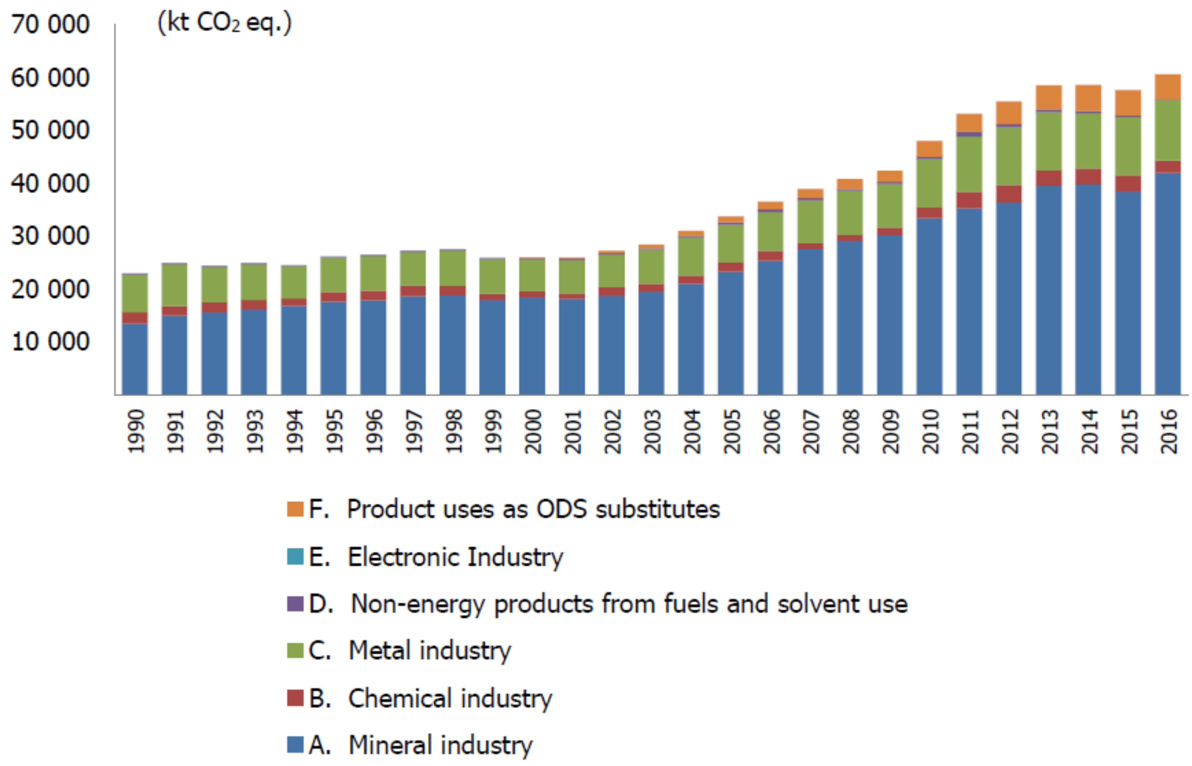

Figure 4: Emissions from IPPU (industrial processes and product use) by subsector, 1990–2016 - Turkish Statistical Office

Within the mineral industry, the major share (85.2%) results from cement production process.

Thus, the most important GHG emission sources of IPPU in 2016 were CO2 eq. emissions from cement production plus iron and steel production, with 7.2% and 2.2% shares of the total national GHG emissions, respectively.

2.5 The non-fuel combustion GHG emissions from Cement Manufacturing

Non -fuel combustion CO2 emissions were estimated by applying a country-specific EF (emission factor) 0.516, in tonnes of CO2 released per tonnes of clinker produced, to the annual national clinker output, corrected with the fraction of clinker that is lost from the kiln in the form of cement kiln dust (CKD) (Turkish Statistical Institute, 2018).

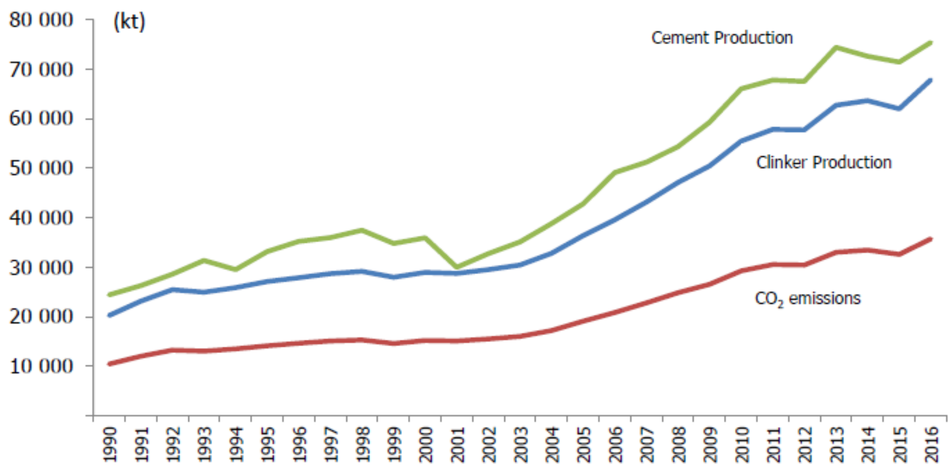

Figure 5: Trend at clinker, cement production and related CO2 emissions, 1990-2016 - Turkish Statistical Office

Turkey started cement production in 1911 and exports in 1978. By 2016, Turkey is Europe's biggest cement producer with 75 million tons of clinker production capacity.

CO2 emissions from cement production (the non-combustion part) increased by 242% between 1990 and 2016. In 2016 clinker production was 67.8 Mt and it generated **35.7 Mt of CO2 emission**. (see annex 1). This represent 57% of the total IPPU emissions.

2.6 The Cement Industry GHG emissions

The cement industry emits in total **55.2 Mt of CO2 eq. in 2016** (19'4+35'7) which is the addition of the "combustion" and the "non-combustion" GHG emissions from cement manufacturing. This is an **average of 813 kg of CO2 eq. per ton of clinker produced**. This represents **11% of the National GHG emissions in 2016**.

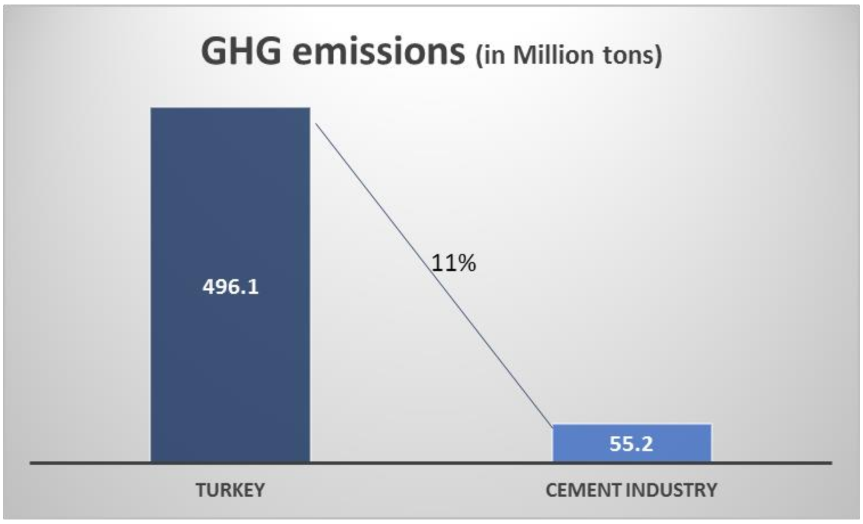

Figure 6: GHG emissions of Turkey and the cement industry in 2016

3. THE CEMENT INDUSTRY POTENTIAL CO2 REDUCTION

Manufacturing of clinker induces two sources of CO2 emissions:

- Non-Fuel Combustion: Chemical decomposition of calcium carbonate (CaCO3). At around 900 °C, calcium carbonate becomes calcium oxide, releasing CO2 into the atmosphere. This represents approximately 65% of the CO2 emitted during clinker manufacture
- Fuel Combustion: Fossil fuel combustion is responsible for the remaining 35%

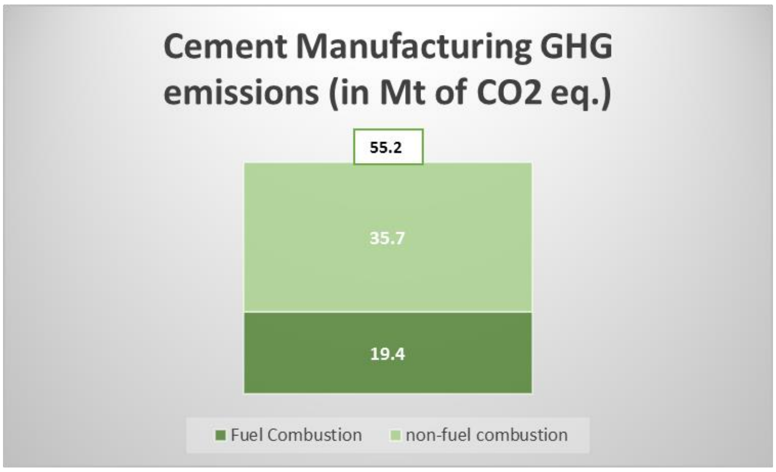

Figure 7: The Cement Manufacturing GHG emissions (in Mt of CO2 eq.) - 2016

There are basically four main CO2 reduction levers in the cement industry that need to be urgently implemented:

e) improving energy efficiency

f) reducing clinker content in cement

g) switching to fuels that are less carbon intensive (e.g. alternative fuels)

h) and implementing innovative technologies such as carbon capture.

3.1 <u>The clinker factor ratio as CO2 reduction lever.</u>

Integrating alternative cement constituents reduces the clinker to cement ratio and thus the CO2. This is by far the most effective CO2 emissions reduction lever.

Turkey consumes mainly CEM I (58%), a cement made mainly with 95% clinker content, and CEM II (32%), a cement which clinker factor can vary. Among the CEM II cement, majority (69%) are type A with between 6% and 20% of possible alternative cement constituents. On average, and according to Cementis calculations, Turkish **clinker factor (clinker content in cement) is around 87%**.

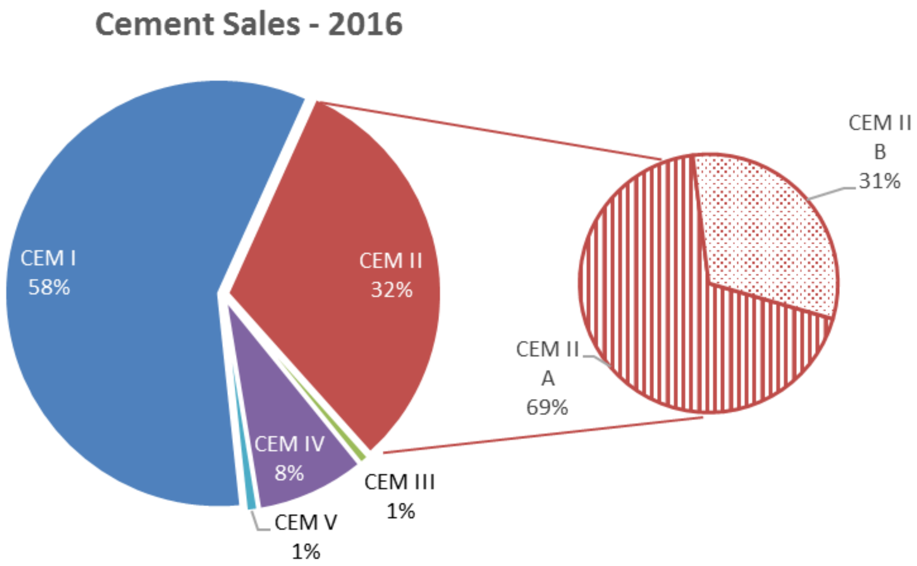

Figure 8: Cement sales by type in 2016 - TCMA (Turkish Cement Manufacturers' Associations, 2016)

If further reduction of clinker factor should be considered, the option of LC3 cement must be implemented (www.LC3.ch) (K. Scrivener, J. Vanderley, E. Gartner, 2016).

Limestone calcined clay cements (LC3) are blended cements that combine clinker, limestone, calcined clay and gypsum. They take advantage of the high reactivity of calcined clay and the synergic reaction between limestone and clay, offering equivalent mechanical performance to normal Portland cement (CEM I / OPC) with clinker factors down to 50%. LC3 while retaining the mechanical behaviour of OPC, some relevant properties such as resistance to chloride ingress and ASR are significantly improved as compared to other cements. Furthermore, limestone and calcined clays are some of the few raw materials available in the quantities required to constitute a technology suitable to cope with the projected cement demand worldwide.

Non-Fuel Combustion CO2 impact on lowering the clinker factor through LC3

Let's assume all CEM I cement volume is replaced by LC3. This means that the average clinker factor of CEM I volume is not anymore 95% but 50% and the other cements (CEM II, III, IV & V) clinker factor stay the same. All cement sold in Turkey would then have a clinker factor 60.9% instead of 87%.

This also means that to produce the same quantity of cement, 30% less clinker would be needed, which represents a decrease of 10.1 Mt CO2 emissions from non-combustion source.

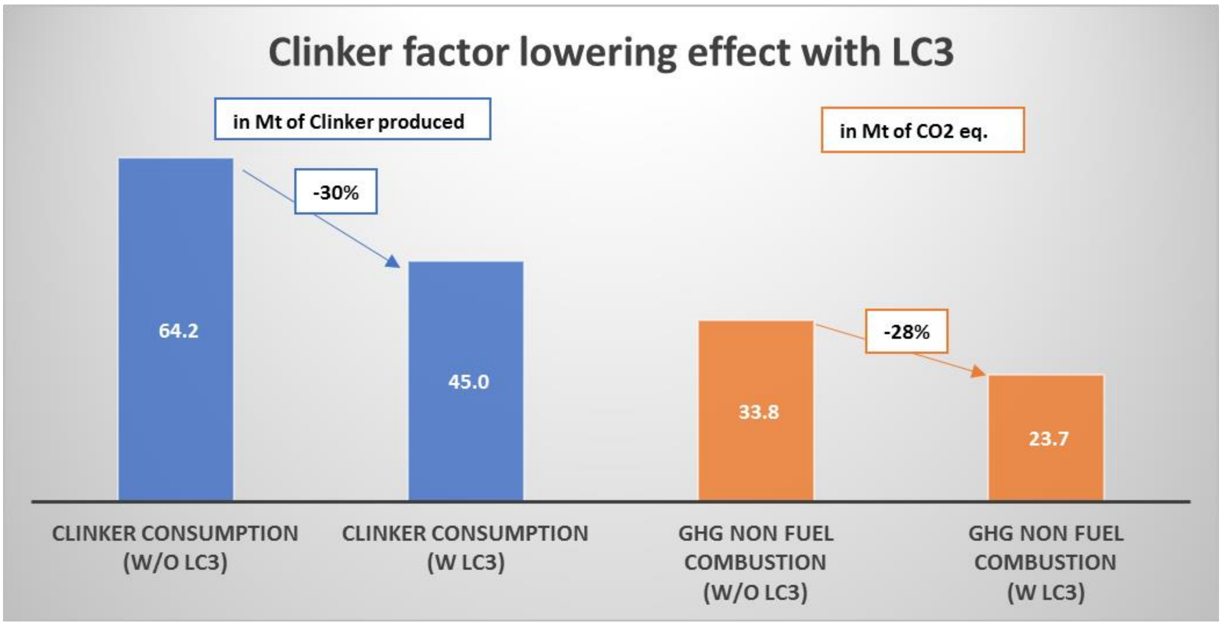

Figure 9: Clinker Factor Lowering Effect with LC3

This decrease represents:

- 28% reduction of the Cement non-fuel combustion GHG
- 2% reduction of the national GHG emissions

Fuel Combustion CO2 impact on lowering the clinker factor through LC3

According to Turkish National Energy Balance 2016, cement factories fuel mix was 44% hard coal and 56% Petroleum coke. The average CO2 emissions from both fuels is around 94 kg of CO2 eq. per GJ.

Shifting all CEM I to LC3 will automatically reduce CO2 emissions from fuel because calcined clay only needs to be heated until 850 °C thus, only 2'600 MJ per ton of calcined clay is needed versus 3'200 MJ per ton of clinker. The delta in CO2 emissions from fuel combustion will be a reduction of 2.3 Mt of CO2 eq.

Thus, for Turkey, replacing CEM I by LC3 would automatically cut CO2 emissions by 12.4 Mt of CO2 eq. (2.3 Mt + 10.1 M).

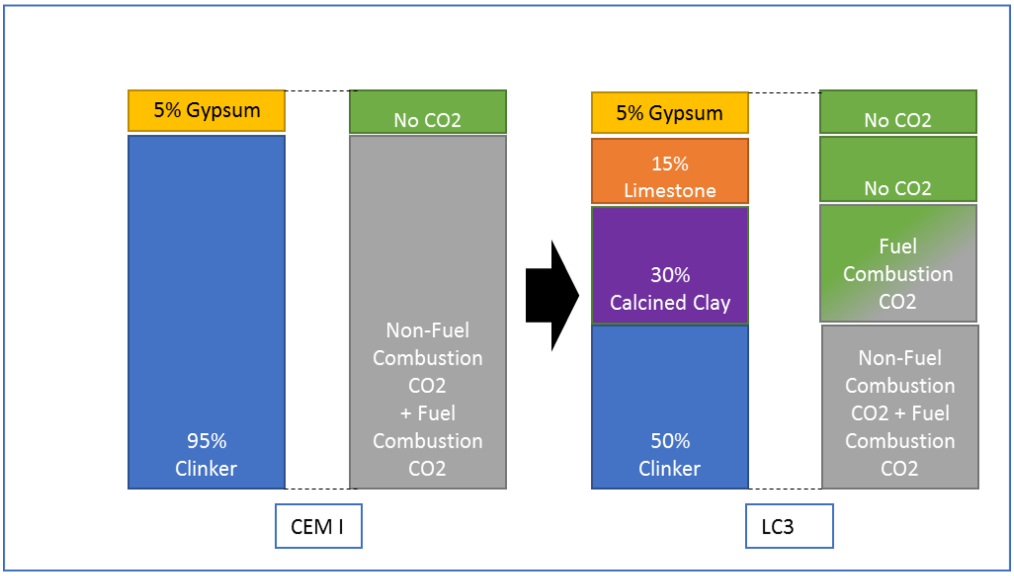

Figure 10: Co2 emissions reduction from a CEM I cement to a LC3 Cement

3.2 Use of alternative fuel for producing the clinker needed

Let's assume the clinker still needed is produced with a mix of coal, petcoke and a certain % of alternative fuel. Knowing that the current mix of coal and petcoke in Turkey emits on average 94 kg of CO2 eq. per GJ, tires emits 85 kg of CO2 eq. per GJ, RDF (Refused Derived Fuel) 75 kg and biomass zero (carbon neutral). A reasonable alternative fuel content in the fuel mix could be 40% of which 10% could be biomass waste with zero CO2 emissions and the rest could be RDF from municipal waste (20%) and tires (10%). The average CO2 emissions from scenario 1 new fuel mix would then be **80 kg of CO2 eq per GJ** as depicted in picture 11 versus the original 94 kg of CO2 eq per GJ (WBCSD CSI, 2013).

	CO2 eq. Emissions/GJ		scenario 1	scenario 2
coal/petcoke	94	kg CO2/GJ	60%	50%
tires	85	kg CO2/GJ	10%	15%
RDF	75	kg CO2/GJ	20%	20%
Biomass	0	kg CO2/GJ	10%	15%
			Avg. 80 kg of CO2 eq. per GJ	**Avg. 75 kg of CO2 eq. per GJ**

Figure 11: CO2 emissions from different fuel mix including waste streams - (WBCSD CSI, 2013)

Scenario 1 fuel mix would reduce CO2 eq emissions by an additional **2.2 Mt** to LC3 production on base of 2016 figures. This figure doesn't consider the avoided CH4 emissions from Municipal solid waste (MSW), and Industrial waste. Scenario 2 would be 3.0 Mt CO2 eq. reduction.

Currently 33.7 million tons of MSW is produced each year in Turkey and **84.4% of it is landfilled** (Turkish Statistical Institute, 2018).

3.3 Summary

If Cement industry in Turkey would adopt the new LC3 cement and incorporate waste streams in its fuel mix, **a total of 14.7 Mt of CO2 eq. would be saved**. **This would bring the total CO2 eq. emissions from the cement industry from 55.2 Mt per year to 40.5 Mt per year (minus 26.5%).** This would represent a 3% national decrease of GHG emissions.

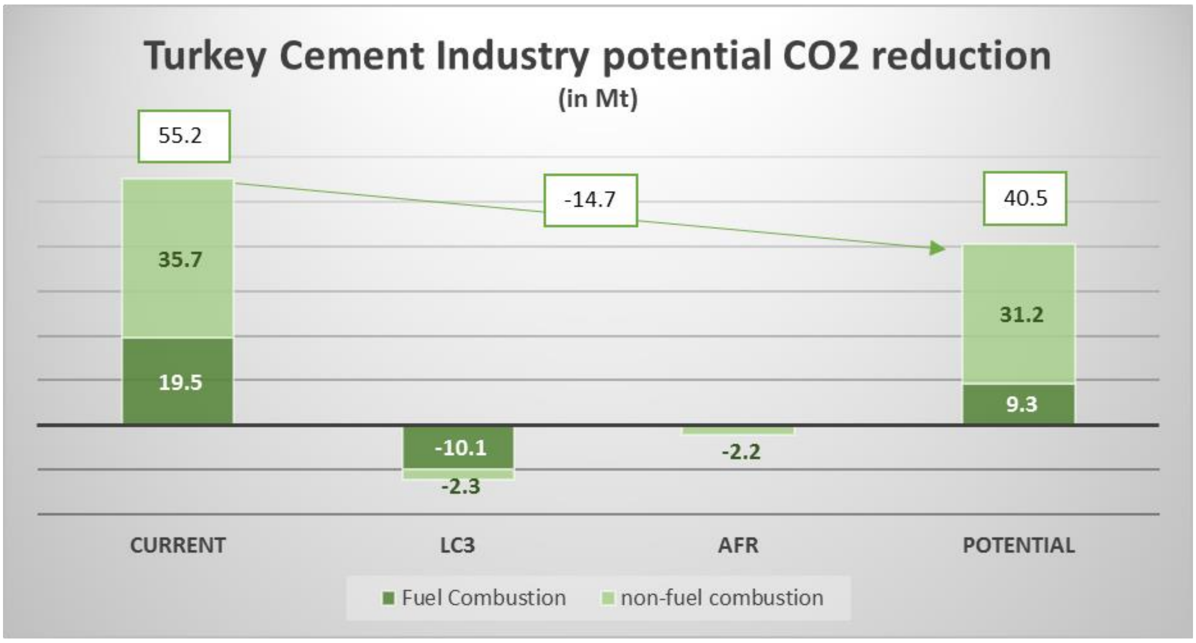

Figure 12: Total potential CO2 reduction per year for the Turkish Cement Industry

4. TURKEY MITIGATION SCENARIO

On September 30th, 2015, Turkey submitted its Intended Nationally Determined Contribution (INDC) to UNFCCC.

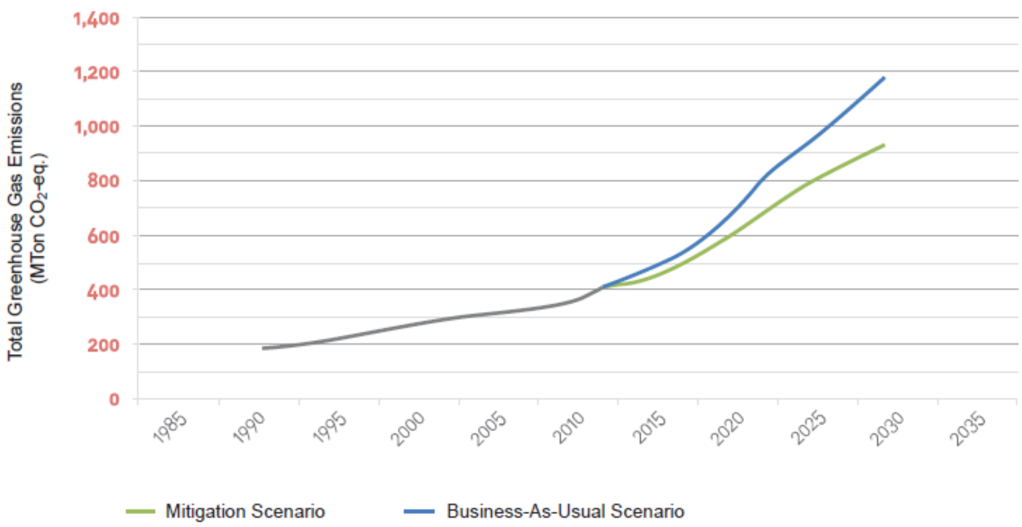

Figure 13: Turkey 2030 GHG emissions - Turkish Statistical Office

The expected 2030 business as usual scenario (BAU) would be 2.5 times 2016 emissions whereas the Mitigation scenario would “only” double them.

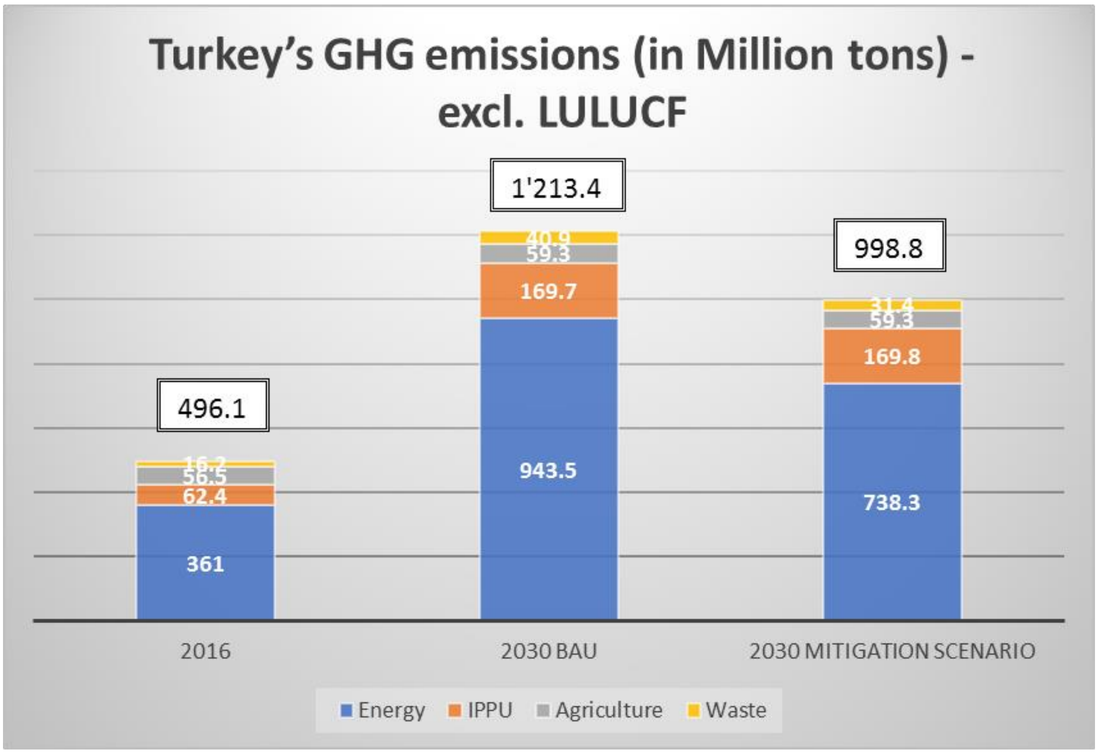

Figure 14: Turkey 2030 scenario versus 2016 emissions - Turkish Statistical Office

Curiously, the mitigation scenario of Turkey does not include any reduction in IPPU or non-fuel combustion CO2 emissions. When in this document 10 million tons CO2 eq. emissions could be saved with the current cement production. The delta with BAU could even be higher in 20130 depending on the future cement production.

5. BIBLIOGRAPHY

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6. ANNEXES

Annex – 1: Non-Combustion CO2 emissions from Cement Production - (Turkish Statistical Institute, 2018)

Table 4.3 CO_2 emissions from cement production, 1990-2016

Year	Clinker Production (kt)	Cemet Production (kt)	CaO Content (%)	CO_2 EF	CKD	CO_2 Emission (kt)
1990	20 252	24 416	64.4	0.506	1.02	10 445
1991	23 153	26 261	64.9	0.509	1.02	12 021
1992	25 489	28 607	65.0	0.510	1.02	13 265
1993	24 941	31 366	65.4	0.513	1.02	13 049
1994	25 880	29 515	65.1	0.511	1.02	13 493
1995	27 094	33 140	65.2	0.511	1.02	14 133
1996	27 852	35 233	65.8	0.516	1.02	14 662
1997	28 706	36 007	65.7	0.516	1.02	15 105
1998	29 148	37 488	65.5	0.514	1.02	15 292
1999	27 966	34 817	65.2	0.511	1.02	14 590
2000	28 950	35 953	65.5	0.514	1.02	15 184
2001	28 746	29 959	65.6	0.515	1.02	15 087
2002	29 499	32 758	65.7	0.516	1.02	15 513
2003	30 419	35 095	65.8	0.516	1.02	16 022
2004	32 779	38 796	65.6	0.515	1.02	17 207
2005	36 382	42 787	65.6	0.515	1.02	19 117
2006	39 569	49 100	65.8	0.516	1.02	20 841
2007	43 174	51 226	65.9	0.517	1.02	22 780
2008	47 095	54 362	65.9	0.517	1.02	24 837
2009	50 436	59 273	65.8	0.516	1.02	26 558
2010	55 485	66 027	65.9	0.517	1.02	29 284
2011	57 823	67 805	66.0	0.518	1.02	30 527
2012	57 758	67 519	65.9	0.517	1.02	30 449
2013	62 736	74 437	65.7	0.516	1.02	32 995
2014	63 642	72 639	65.7	0.516	1.02	33 472
2015	61 971	71 419	65.8	0.516	1.02	32 619
2016	67 856	75 403	65.8	0.516	1.02	35 716