Limestone Calcined Clay Cement LC3

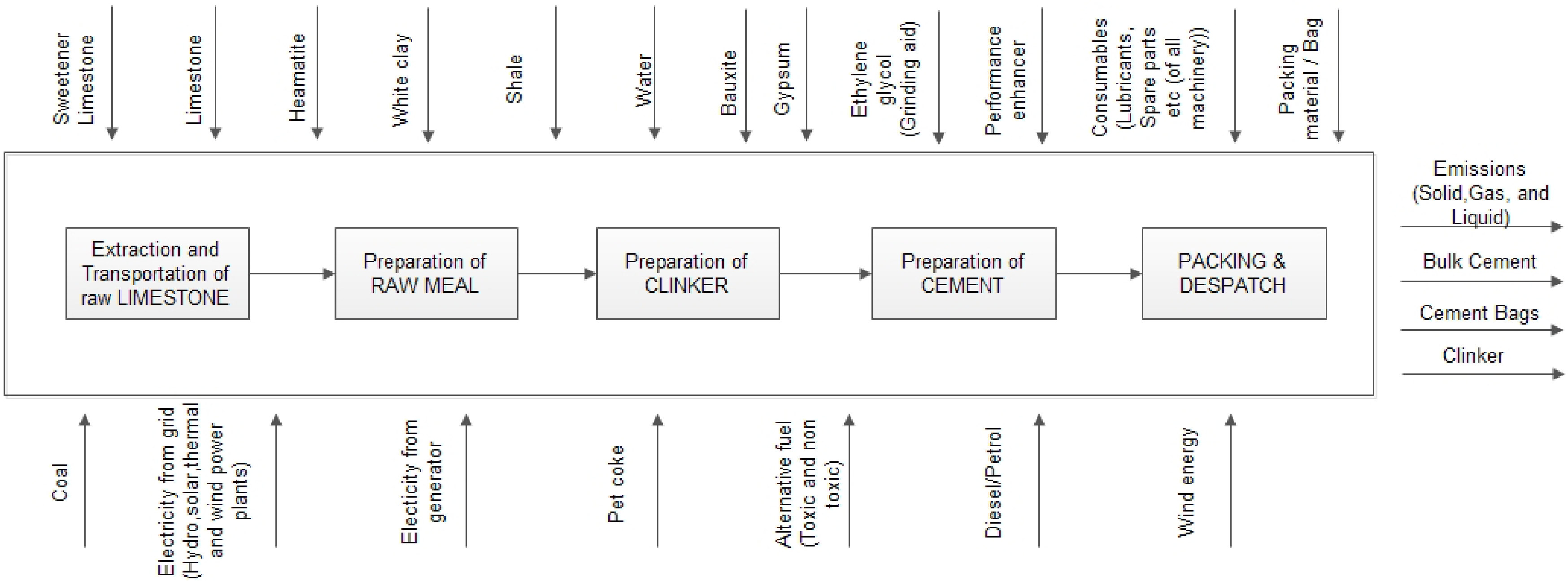
Life Cycle Assessment:

CO_2 Emissions and Energy Calculations

Work Update: January 2016

TARA

Process Map for a Typical Cement Plant in India – *Ordinary Portland Cement (OPC)*



Major raw materials: Limestone, Coal, Pet coke, Lignite

Other significant inputs: Electricity (from the grid), Alternative fuels, Gypsum, Clay, Water, Plant and equipment

Important sub-processes: Limestone extraction, Raw meal preparation, Clinkerization, Blending, Packing and dispatch, Power generation

Products: Bulk cement, Cement bags, Clinker

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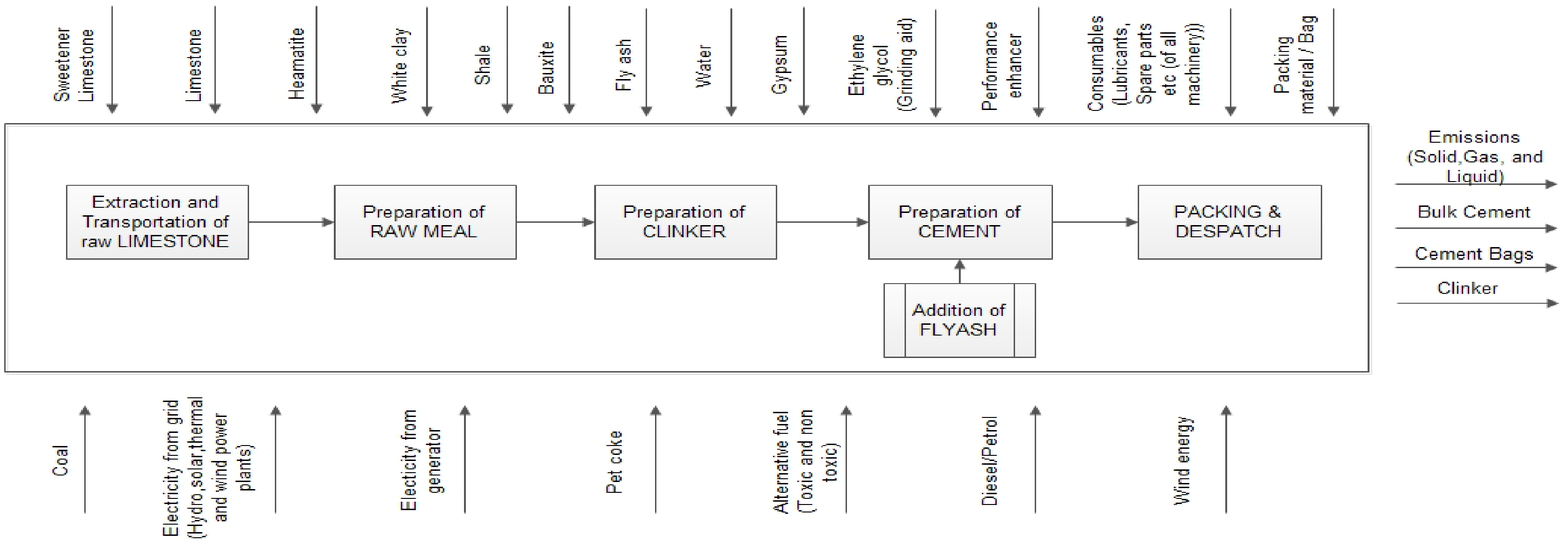
Process Map for a Typical Cement Plant in India – *Fly Ash Based Portland Pozzolana Cement (PPC)*



Major raw materials: Limestone, *Fly ash*, Coal, Pet coke, Lignite

Other significant inputs: Electricity (from the grid), Alternative fuels, Gypsum, Clay, Water, Plant and equipment

Important sub-processes: Limestone extraction, Raw meal preparation, Clinkerization, *Fly ash transport*, Blending, Packing and dispatch, Power generation

Products: Bulk cement, Cement bags, Clinker

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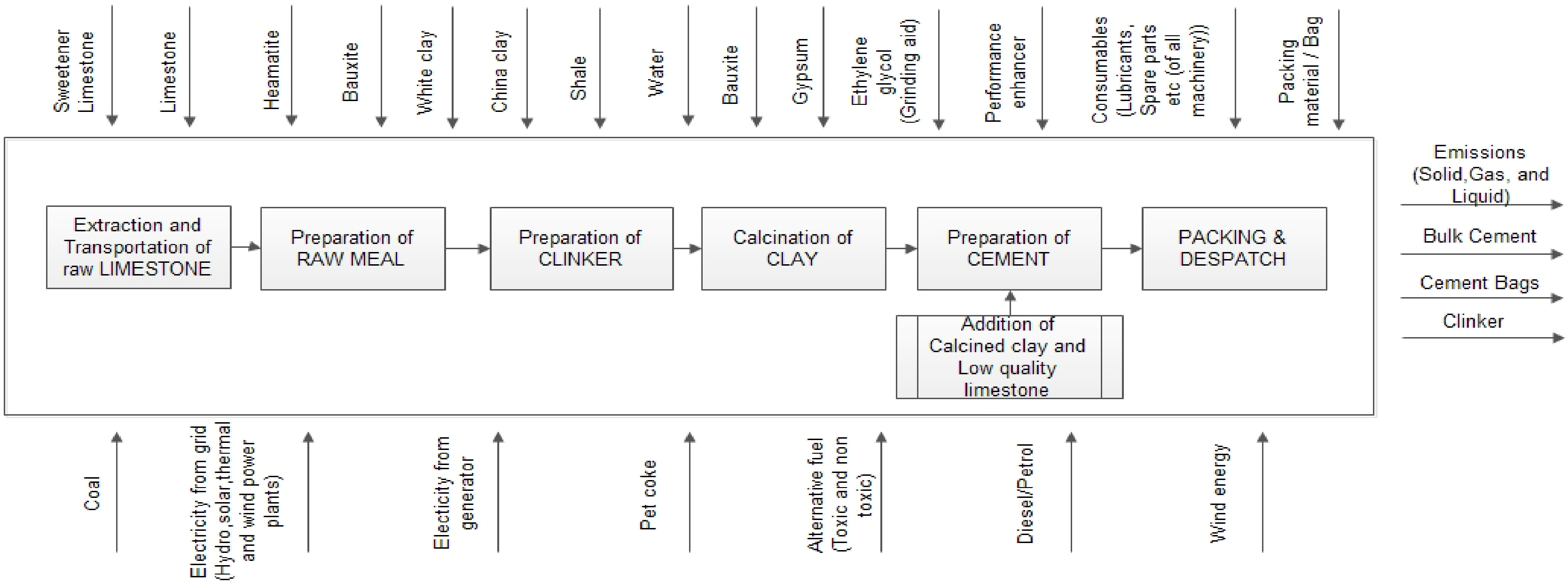
Potential Process Map for LC³ Production in a Typical Indian Cement Plant



Major raw materials: Limestone, *Kaolinitic clay*, Coal, Pet coke, Lignite

Other significant inputs: Electricity (from the grid), Alternative fuels, Gypsum, White clay, Water, Plant and equipment

Important sub-processes: Limestone extraction, Raw meal preparation, Clinkerization, *Clay calcination*, Blending, Packing and despatch, Power generation

Products: Bulk cement, Cement bags, Clinker

Limestone Calcined Clay Cement LC3

System Boundaries Considered

- **Ground-to-Gate (Cradle-to-Gate)**
  - *From mines to gate of the cement plant*
  - Energy requirements and CO_2 emissions (direct and indirect) are considered from all processes involved in the production of cement, including
    - Extraction and transportation of all fuels & raw materials
    - Energy and emission in the production of electricity
  - Energy and emission from production of alternative fuel and fly ash consumed are excluded.

System Boundaries Considered

- **Gate-to-Gate**
  - *Processes undertaken by the cement plant*
  - All direct raw material and energy requirements, and emissions are considered from all processes undertaken by the cement plant, including
    - Extraction of Limestone
    - Transportation of fly ash, clay, gypsum, and filler limestone.
  - Extraction and transportation of fuel are excluded

Limestone
Calcined
Clay
Cement

System Boundaries Considered

- **CSI (Cement Sustainability Initiative, WBCSD) System*****
  - *From mines to gate of the cement plant*
  - Energy requirements and CO_2 emissions from fuels within the cement plant (Only company owned activities)
  - Extraction of raw materials and transportation outside the plant, and impacts of alternative (biomass and waste) fuels are excluded

****** *As per CO_2 and Energy Accounting and Reporting Standard for the Cement Industry, CSI, 2011.*

Limestone Calcined Clay Cement LC3

Impact Assessment - Case Study (Reddipalayam,Ariyalur)

- Ariyalur, Tamil Nadu, India, has rich limestone deposits. Consequently, many cement plants are located there.
- It is considered that the plant has been leased limestone quarries adjacent to its location. Since the limestone is soft in this region, it is extracted by excavation without blasting. The material used has a composition with about 44% CaO, 12.5% SiO_2, 10% moisture and 35.5% loss on ignition.
- It is considered that Class F Fly ash is transported from the Mettur Power Plant (over 200 km), with a composition of 61% SiO_2 , 27% Al_2O_3 and 4% Fe_2O_3.
- It is considered that waste phosphogypsum is transported from Tutticorin (385 km)

Impact Assessment - Case Study (Reddipalayam,Ariyalur)

- Most of the energy required is obtained by burning coal and pet coke. 10% of the energy in the cement kiln is produced by burning biomass and alternative fuels
- Most of the electricity (80%) is considered as generated by a captive thermal power plant burning pet coke (88% contribution in terms of power produced) and lignite (11%). The plant also produces some fly ash that is added to the limestone for the raw meal
- Water consumption of the plant is about 0.2 m^3 per ton of cement

Limestone Calcined Clay Cement LC3

Values Assumed for LC^3 Calculations

- LC^3 has the composition of 50% clinker, 30% calcined clay, 15% crushed limestone and 5% gypsum
- Mass loss in clay during calcination (including drying and dehydroxilation) is 13%
- Energy consumption for calcination of clay is taken as 2.6 MJ/kg (including 30% losses)
- Coal is assumed to be used for the calcination of the clay, and emissions are calculated based on the carbon content of coal.
- Electricity required for calcining rotary kiln is assumed to be 0.04 kWh/kg of raw clay or 0.15 MJ/kg of clay
- Fuel consumption for transportation is based on trucks or bunkers with 23 ton freight capacity and 3km/litre and 4km/litre mileage when full loaded and empty loaded.
- Hypothetically, it is assumed that clay can be sourced from Dharmapuri (104 km away), and transported to and calcined at the cement plant

Limestone Calcined Clay Cement LC^3

Cements: CSI System Calculations

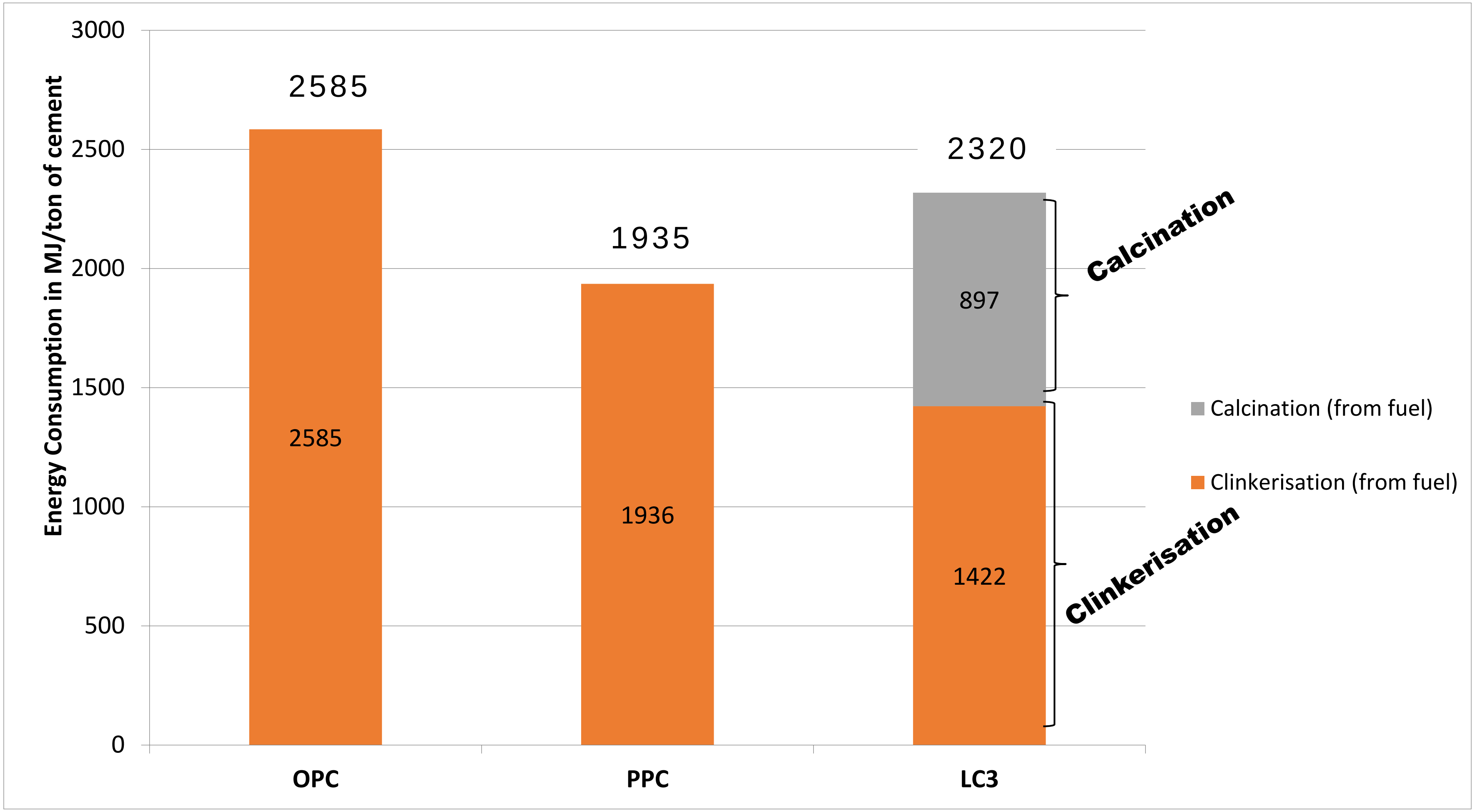
- Only direct emissions are considered.
- Emissions and energy consumption during extraction and transportation of raw materials and all fuels are excluded.
- Emissions and energy consumed due to the production of electricity (both purchased and produced) is excluded.
- *Provides data for comparison with CSI database*
- *Based on measurable quantities at the plant level and avoids almost all assumptions that are not relevant to local conditions and materials.*

Impact	OPC	PPC	LC^3	CSI (India, 2012): 70.5% clinker factor
Energy consumed (MJ/ton of cement)	**2585**	**1935**	**2320**	2400*
Emission of CO_2 (kg/ton of cement)	**695**	**520**	**475**	580*

*values shown for comparison

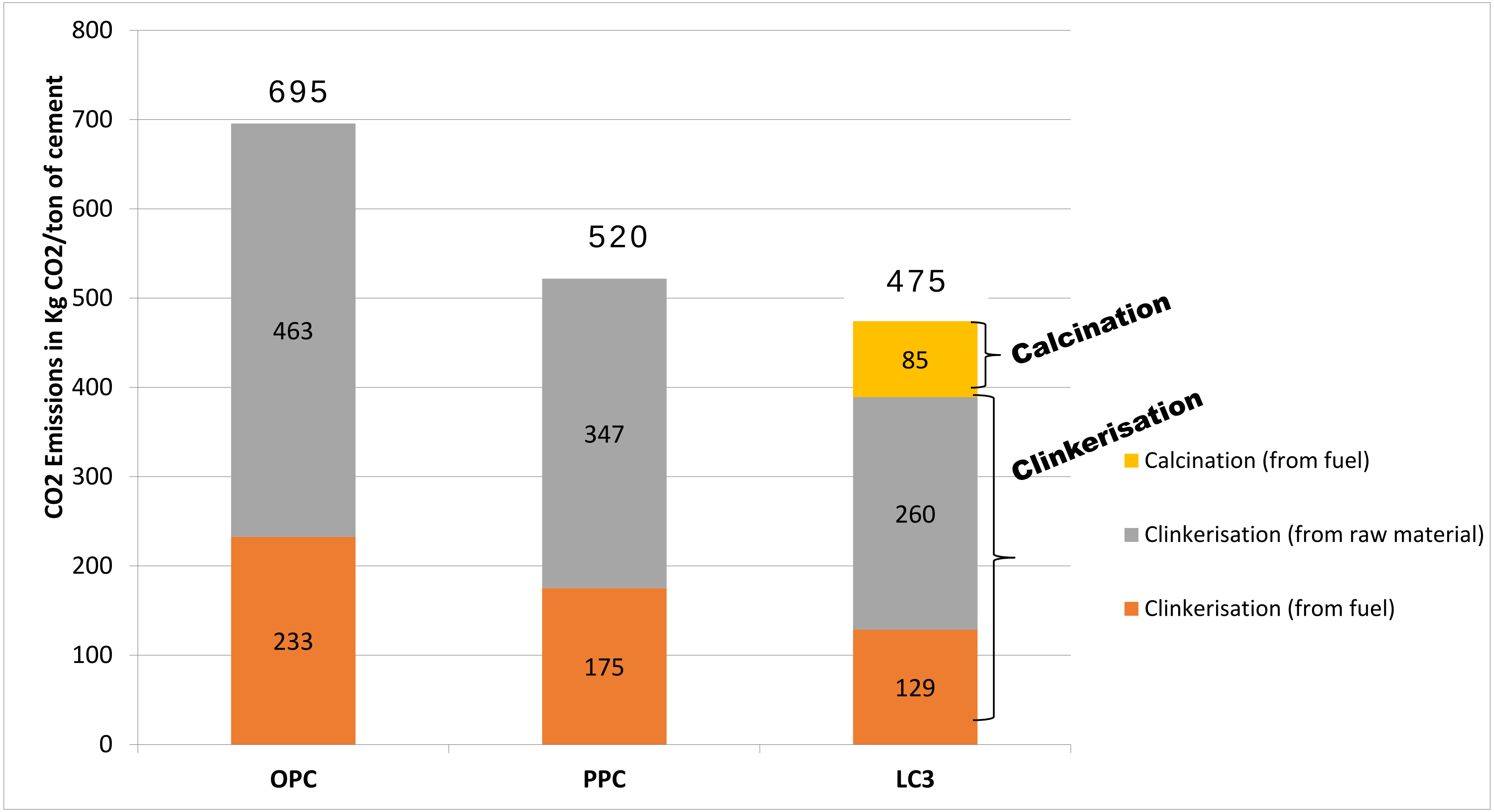
Limestone Calcined Clay Cement LC^3

Processwise Energy Consumption (CSI System)



Limestone Calcined Clay Cement

Processwise CO_2 Emissions (CSI System)



Limestone Calcined Clay Cement LC3

LCA Ground-to-Gate Calculations: **Concrete**

Limestone
Calcined
Clay
Cement

Assumptions

- Distances from raw material locations are as follows:

COMPONENTS	ORIGIN	DISTANCE (km)
Cement	Ariyalur	307
Sand	Villupuram	192
Fly ash	Mettur	360
Coarse Aggregate	Kanchipuram	75
Gypsum	Tutticorin	400
Clay	Dharmapuri	104

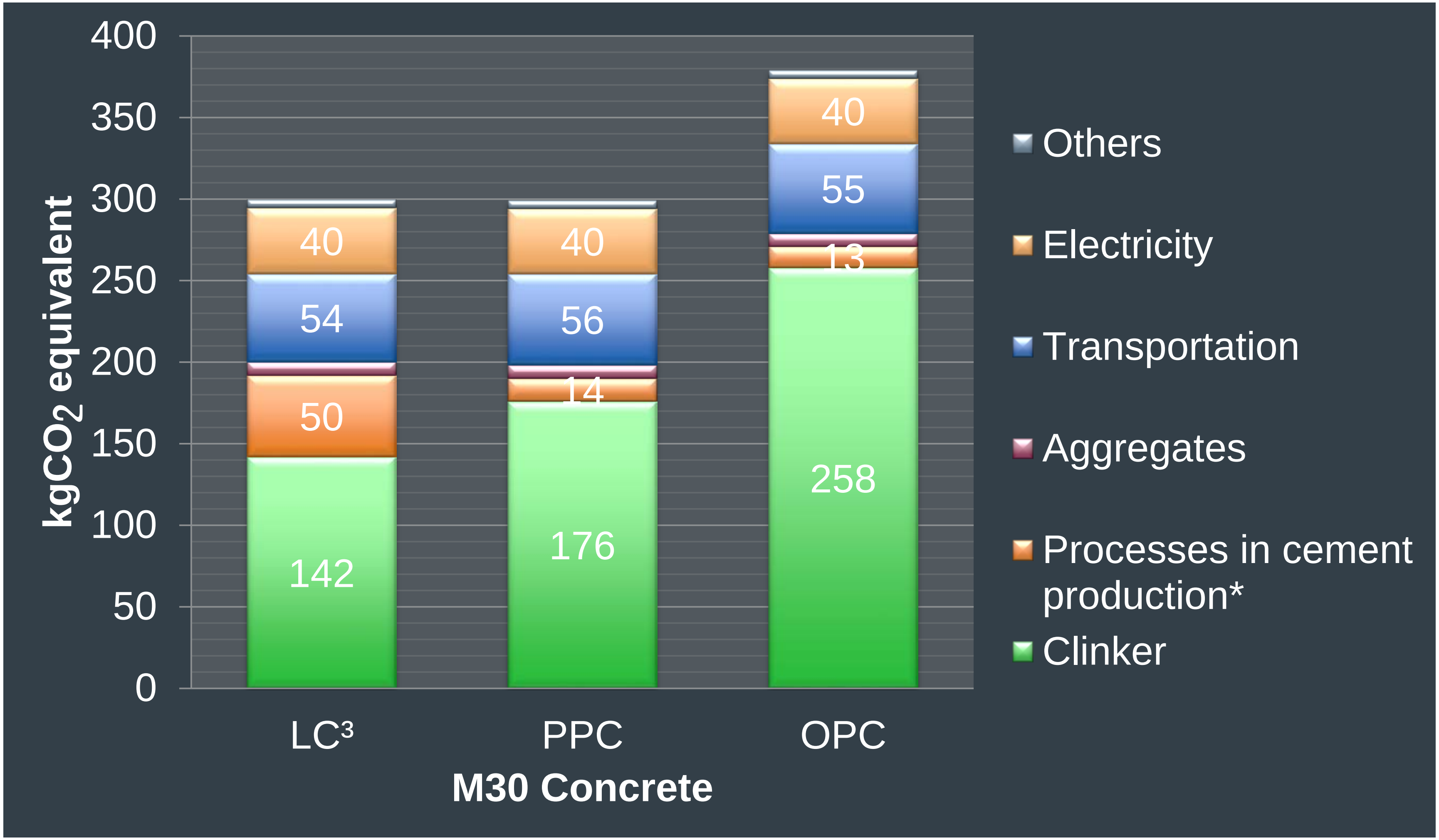
Mix Designs: M30

COMPONENTS (kg)	M30 OPC	M30 PPC (FA30)	M30 LC^3
Cement	310	310	310
Water	159	142	155
Coarse Aggregate	1222	1232	1222
Fine aggregates	706	716	715

LC^3-50 (56) (2:1) IB 01/15

Limestone Calcined Clay Cement

kgCO_2-equivalent for M30 concrete



*Includes contribution of processes in cement production in kg CO_2 other than clinker

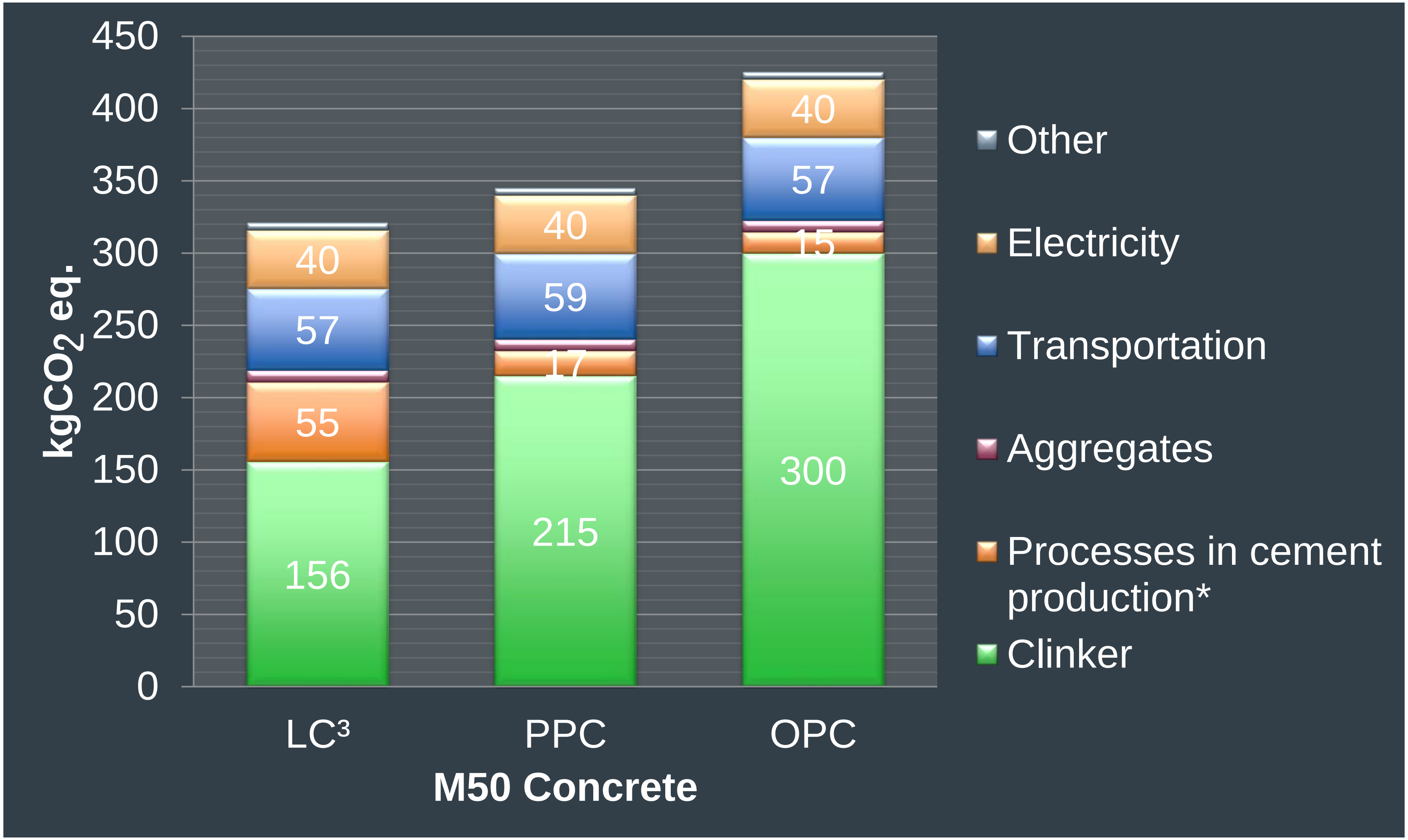
Limestone Calcined Clay Cement LC3

Mix Designs: M50

COMPONENTS (kg)	M50 OPC	M50 PPC (FA30)	M50 LC^3
Cement	360	380	340
Water	144	133	136
Coarse Aggregate	1193	1188	1220
Fine aggregates	703	699	704

LC^3-50 (56) (2:1) IB 01/15

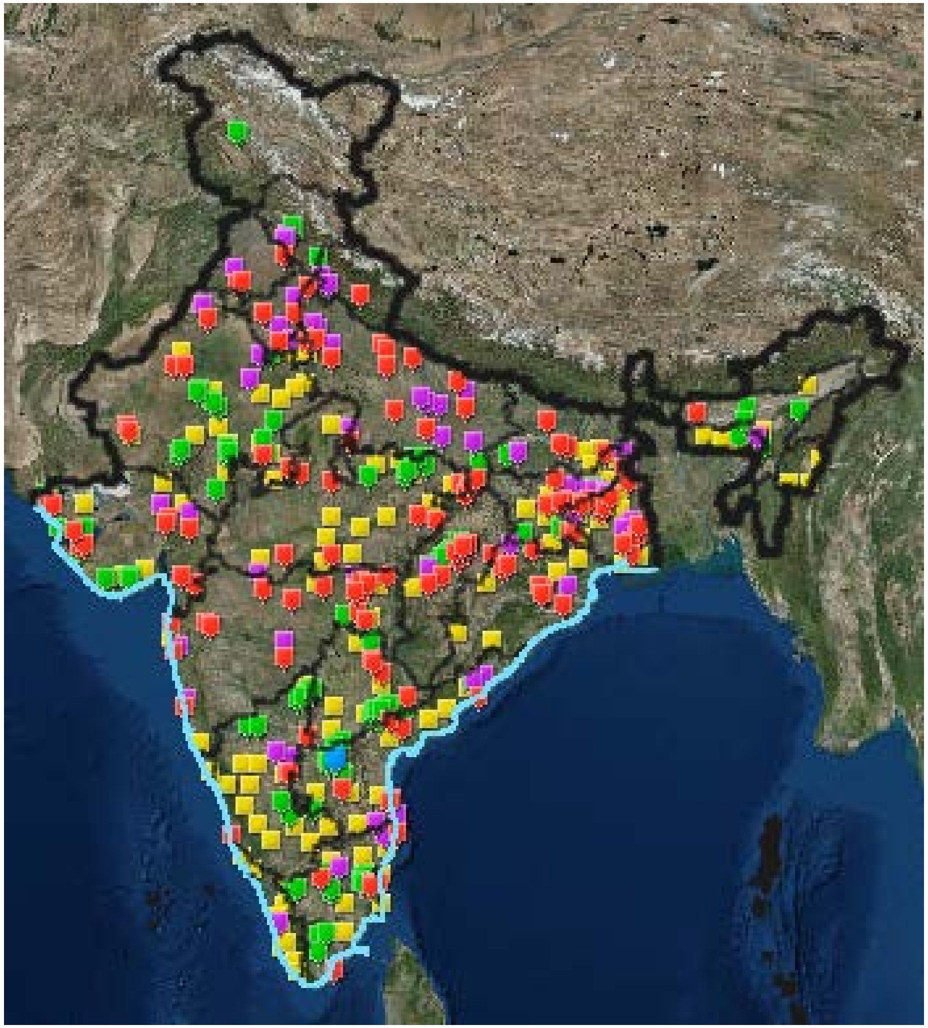
kgCO_2-equivalent for M50 concrete



*Includes contribution of processes in cement production in kg CO_2 other than clinker

Limestone Calcined Clay Cement LC3

GIS Tool Prepared by TARA



http://dagroup.maps.arcgis.com/apps/webappviewer/index.html
?id=c570f9a7ae0f4a0c9f61cac87fda8fac

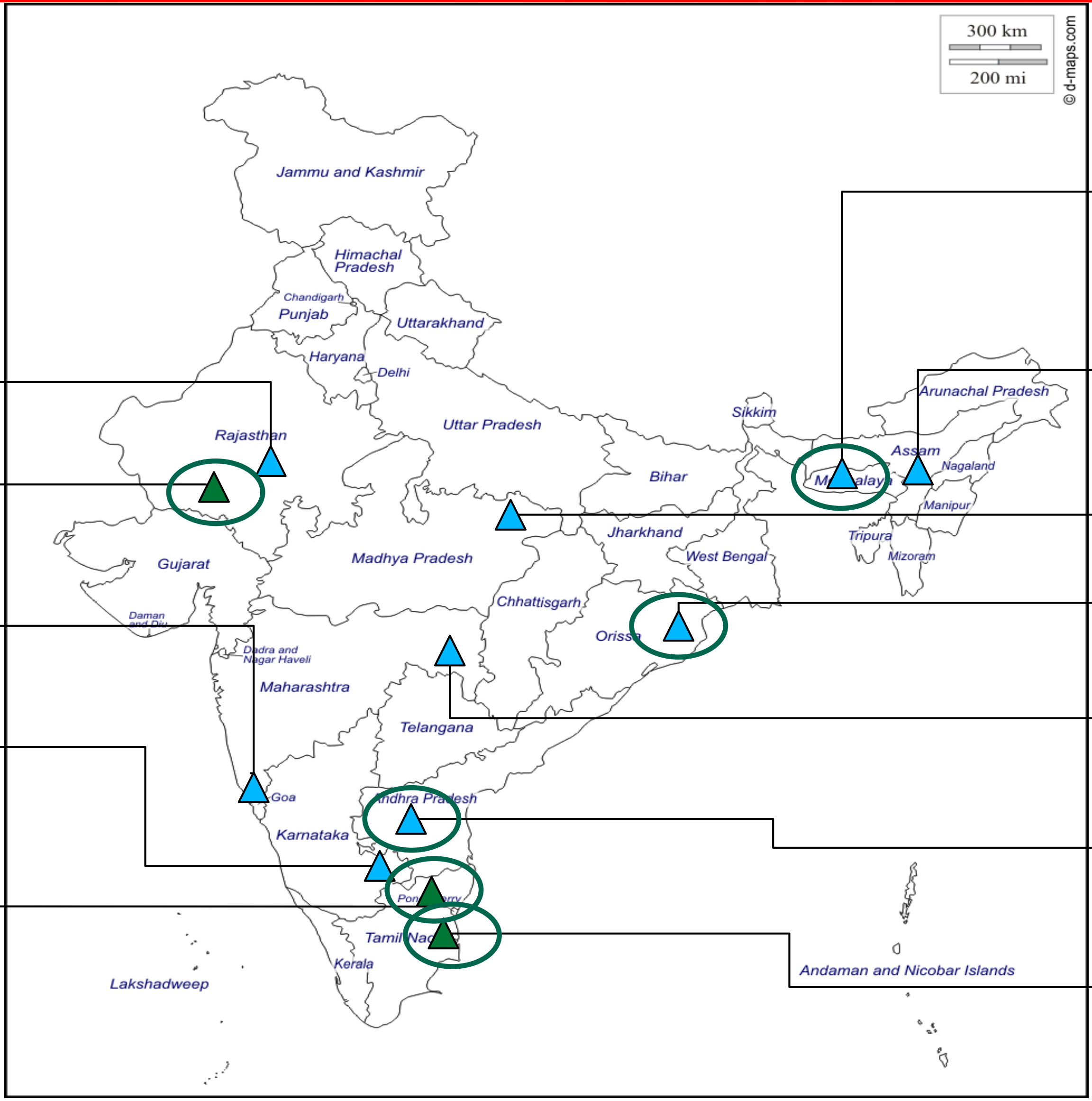
- **Shows locations of cement plants, clay mines, thermal power plants, ports, and railway stations**
- **Facilitates identification of nearest clay and fly ash source and calculation of transportation distances**
- **Will help identify potential locations for LC^3 plants**

For LCA, the GIS Tool is used to obtain locations of nearest clay mines and thermal power plants for transportation distance calculations

Limestone Calcined Clay Cement LC3

Plant Visits - Status

- ▲ Visited
- ▲ Proposed to be visited



- Shree Cement, Ras
- J.K. Laxmi,Sirohi
- Lafarge, Pilerne
- ACC Cement, Bangalore
- Ultratech (Grinding Unit) Arrakonam
- Adhunik Cement (Dalmia), Thangskai
- Calcom, Umrangso
- Satna
- Dalmia Bhubaneshwar
- ACC Cement, Chandrapur
- Ultratech, Tadipatri
- Dalmia and Ultratech Ariyalur

Limestone Calcined Clay Cement LC3

THANK YOU

LCA Team

IIT Madras: Ravindra Gettu, Sivakumar Palaniappan, Sanoop Prakasan, Aanchal Patel, Anusha S. B.

TARA: Soumen Maity, Vaibhav Rathi, Krithi Nagrath, Avanindra Kumar

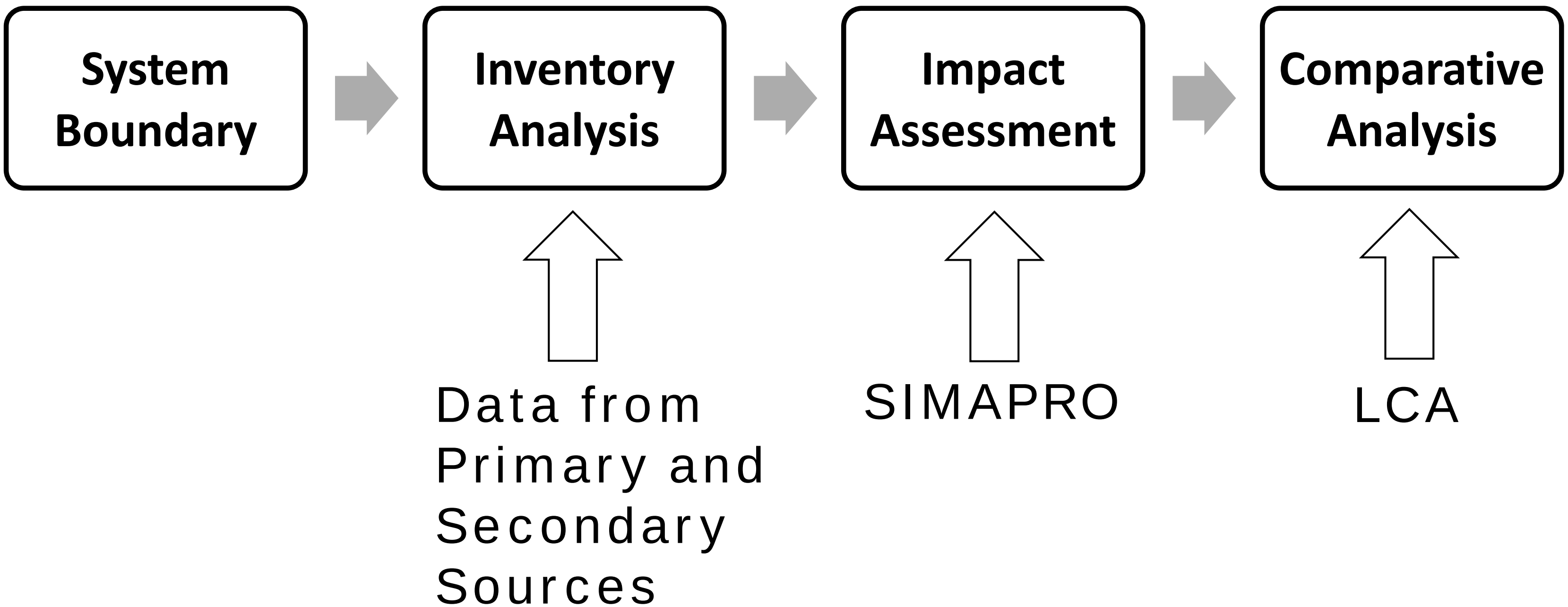
IIT Delhi: Shashank Bishnoi

Advice given by Guillaume Habert is gratefully acknowledged

Software used: SimaPro (PRé Consultants bv)

Limestone Calcined Clay Cement LC3

Work Progress



Inventory of Inputs

Raw Materials	Fuels	Electricity
Limestone	Coal	Purchased from Grid
Clinker	Pet Coke	Generated Onsite
Calcined Clay	Diesel	
Fly Ash	Petrol	
Gypsum	Alternative Fuels (Tyres, Plastics, etc.)	
White Clay	Biomass Fuels (Wood, Paper, etc.)	
Iron Ore		
Shale		
Bauxite		
Haematite		

Minor contributions: Infrastructure, Equipment

Conversion Factors

Calculation of energy content of fuels

High Priority

Low Priority

- **Experimental data – Bomb Calorimetry**
- **Cement plant**
- **EPA – 2014**
- **IPCC 2006**
- **Ecoinvent 3 database**

Calculation of CO_2 Emissions

High Priority

Low Priority

- **Experimental data – CHNS analyzer**
- **EPA – 2014**
- **CSI Protocol**
- **IPCC 2006**
- **Ecoinvent 3 database**

Conversion Factors Used – Indirect emissions and energy

Conversion Factors from Simapro_Ecoinvent database			
Energy (MJ/kg)		**Emission (kg CO_2/kg)**	
Raw Material		**Raw Material**	
Clays, gypsum and limestone (average)	0.046, 0.041 and 0.030	Clays, gypsum and limestone (average)	0.003, 0.003 and 0.002
Fuel		**Fuel**	
Pet coke	33.61	Pet coke	3.14
Diesel Oil	46.27	Diesel Oil	3.72
Lignite	15.19	Lignite	1.38
Coal	27.41	Coal	2.62
Electricity Production (MJ/kWh)	13.4	Electricity Production (kg CO_2/kWh)	1.088
Transportation (MJ/ton-km)		**Transport Means (kgCO_2/ton-km)**	
Lorry	0.44	Lorry	0.077

Limestone Calcined Clay Cement

Material Input for 1 kg of Cement

Input	Unit	OPC	PPC	LC3
Materials/Fuels				
Limestone	kg	1.31	0.99	0.73
Gypsum	kg	0.04	0.04	0.05
White Clay	kg	0.06	0.04	0.39
China Clay	kg	-	-	0.34
Filler limestone	kg	0.05	-	0.15
Fly Ash	kg		0.29	-
Lignite	kg	0.03	0.02	0.02
Tyre	kg	0.001	0.001	0.0003
Plastic	kg	0.007	0.005	0.0042
Paint Sludge	kg	0.002	0.001	0.0013
Coal	kg	0.0001	0.0007	0.0005
Pet Coke	kg	0.054	0.04	0.03
Diesel	kg	0.00004	0.00003	0.00002
Electricity/Heat				
Electricity, Medium voltage (IN)	kWh	0.083	0.066	0.066
Distance				
Clay	km	5	-	-
Fly Ash	km	-	200	-
Gypsum	km	400	400	400
China Clay	km	-	-	104

Cements: Ground-to-Gate Calculations

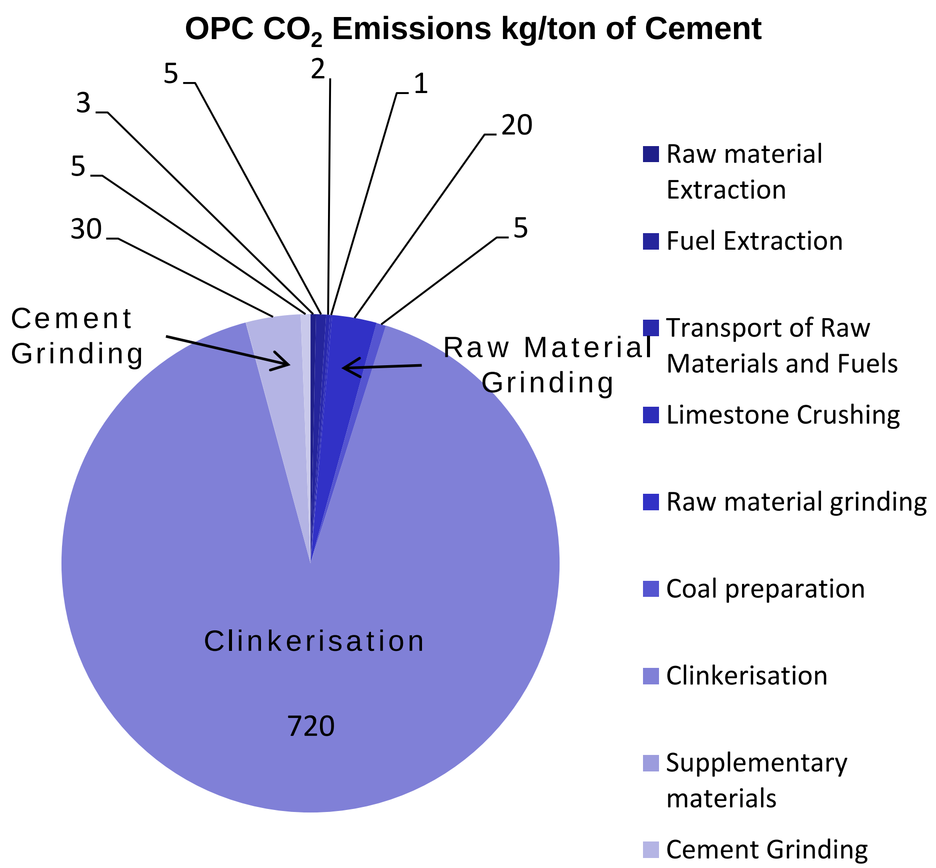
- All processes from extraction of raw materials to their end use is accounted for in emissions and energy consumption.
- Emissions and energy from the extraction of fuels and the production of electricity is also attributed to cement production.
- *Gives a complete (academic) value for life cycle assessment*
- *Many assumptions made are not relevant to local conditions and materials, which could distort the results considerably.*

Impact	OPC	PPC	LC^3
Energy consumed or Embodied energy (MJ/ton of cement)	**3810**	**2980**	**3430**
Emission of CO_2 (kg/ton of cement)	**795**	**610**	**565**

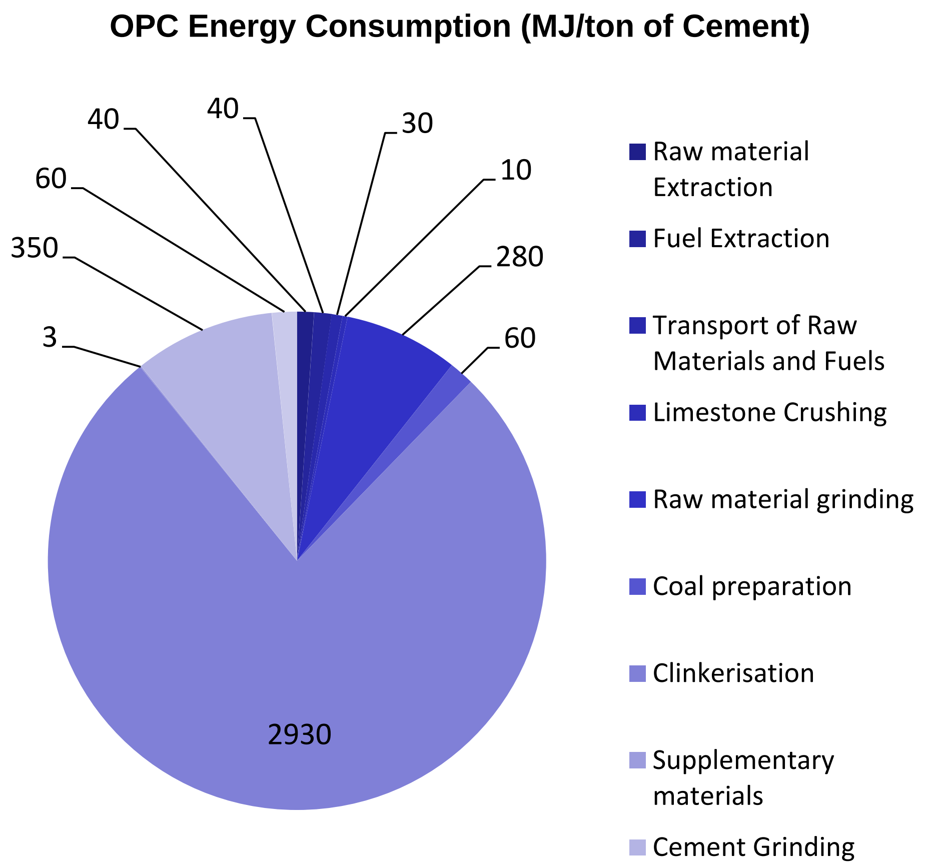
*values shown for comparison

Limestone Calcined Clay Cement LC^3

Processwise breakup for OPC – Ground to gate



Total CO_2 Emissions: 795 kg/ton of Cement

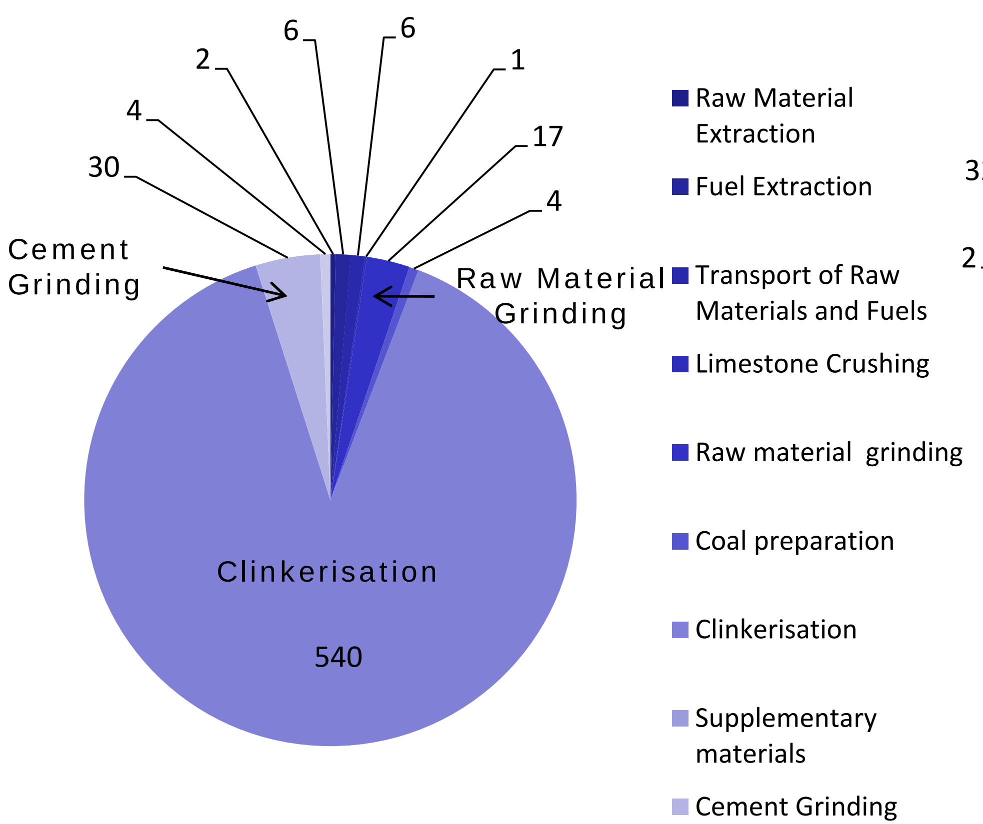


Total Energy Consumption: 3810 MJ/ton of Cement

Limestone Calcined Clay Cement

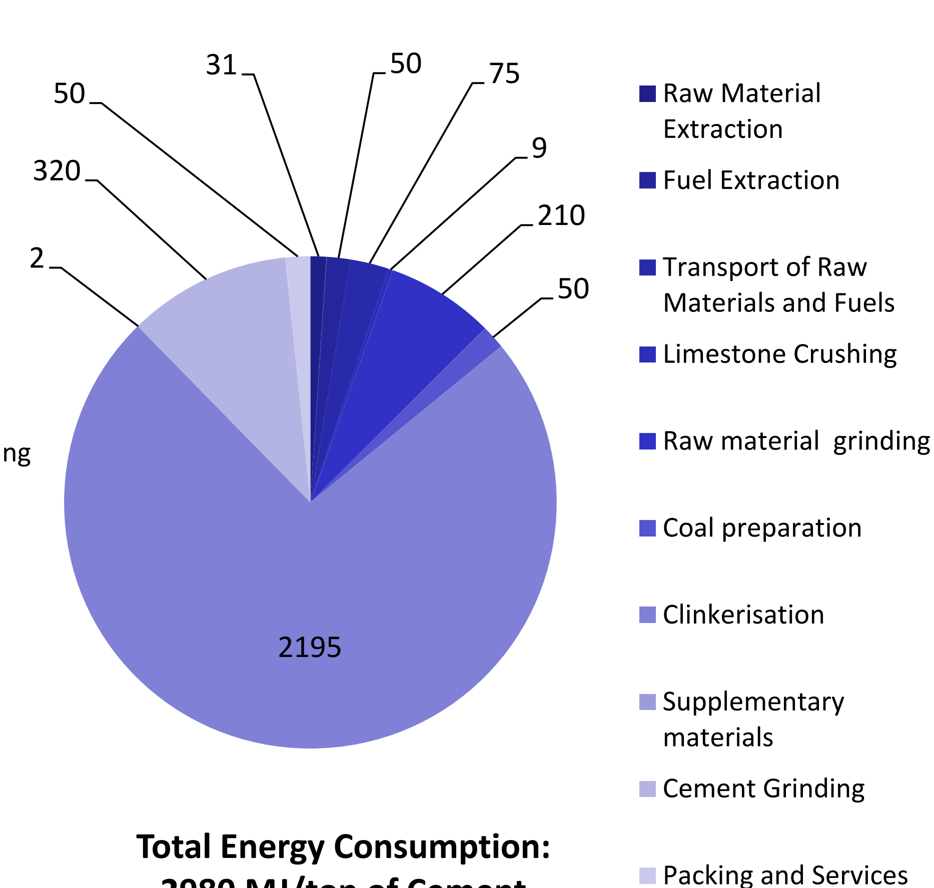
Processwise breakup for PPC – Ground to gate

PPC CO_2 Emissions kg/ton of Cement



Total CO_2 Emissions: 610 kg/ton of Cement

PPC Energy Consumption (MJ/ton of Cement)

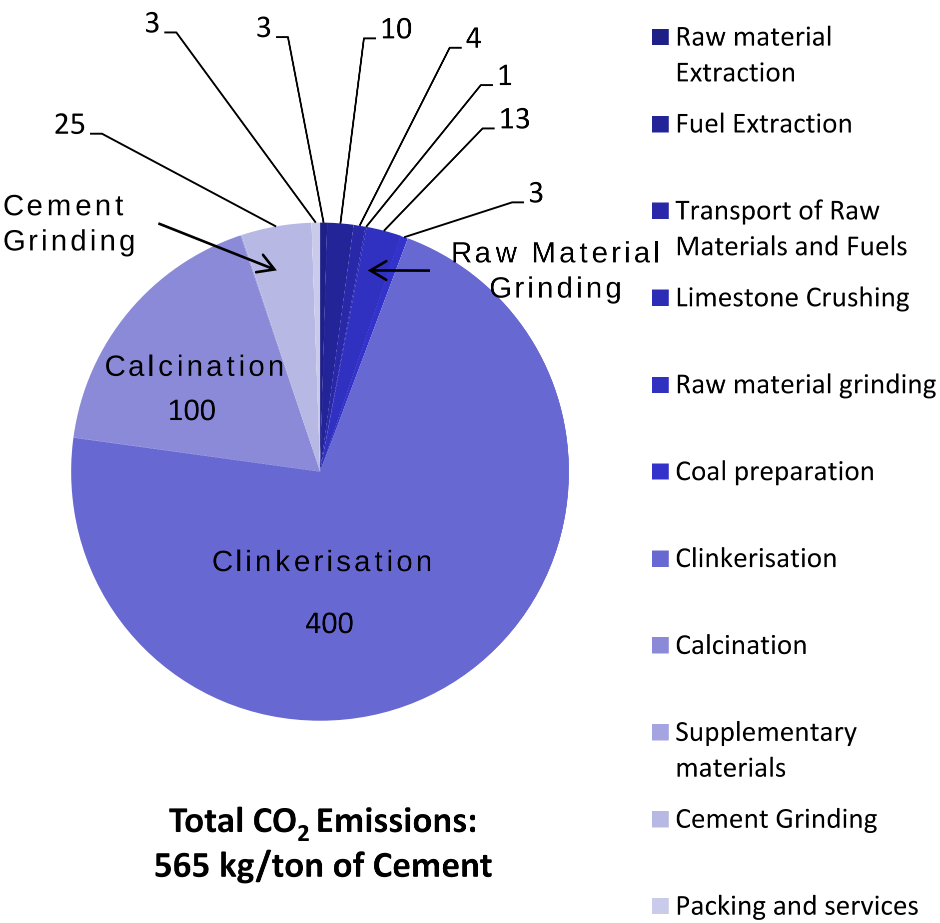


Total Energy Consumption: 2980 MJ/ton of Cement

Limestone Calcined Clay Cement LC3

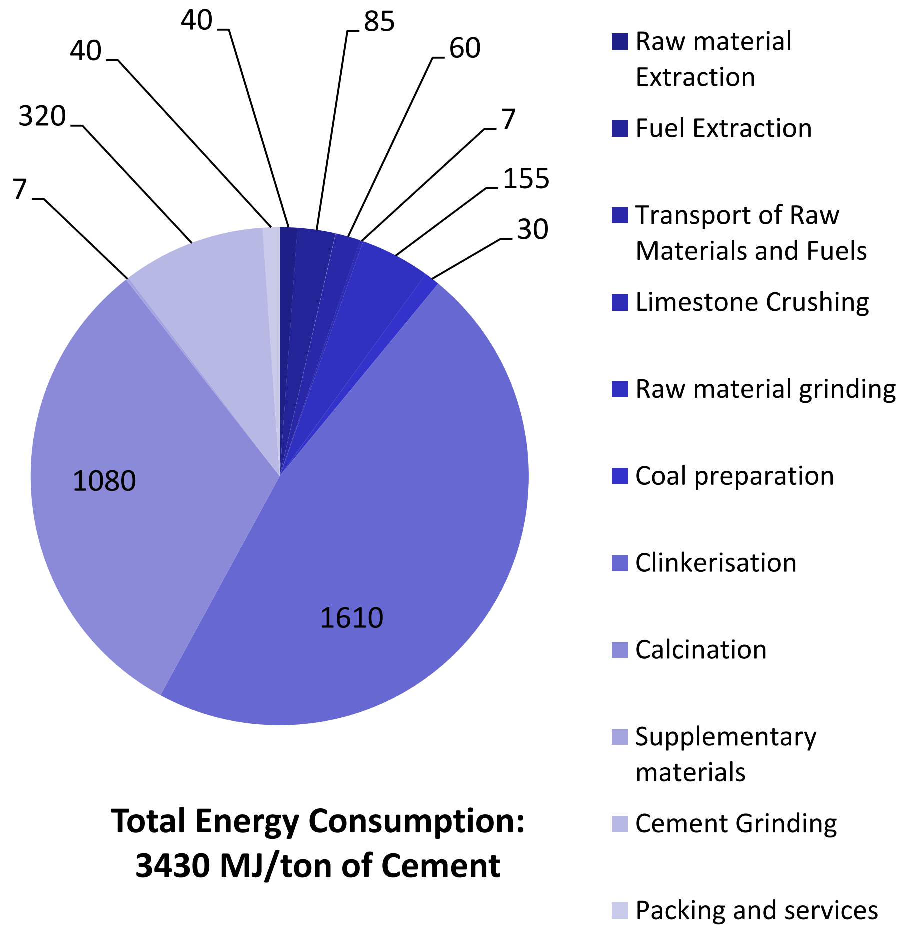
Processwise breakup for LC3 – Ground to gate

LC3 CO_2 Emissions kg/ton of Cement



Total CO_2 Emissions:
565 kg/ton of Cement

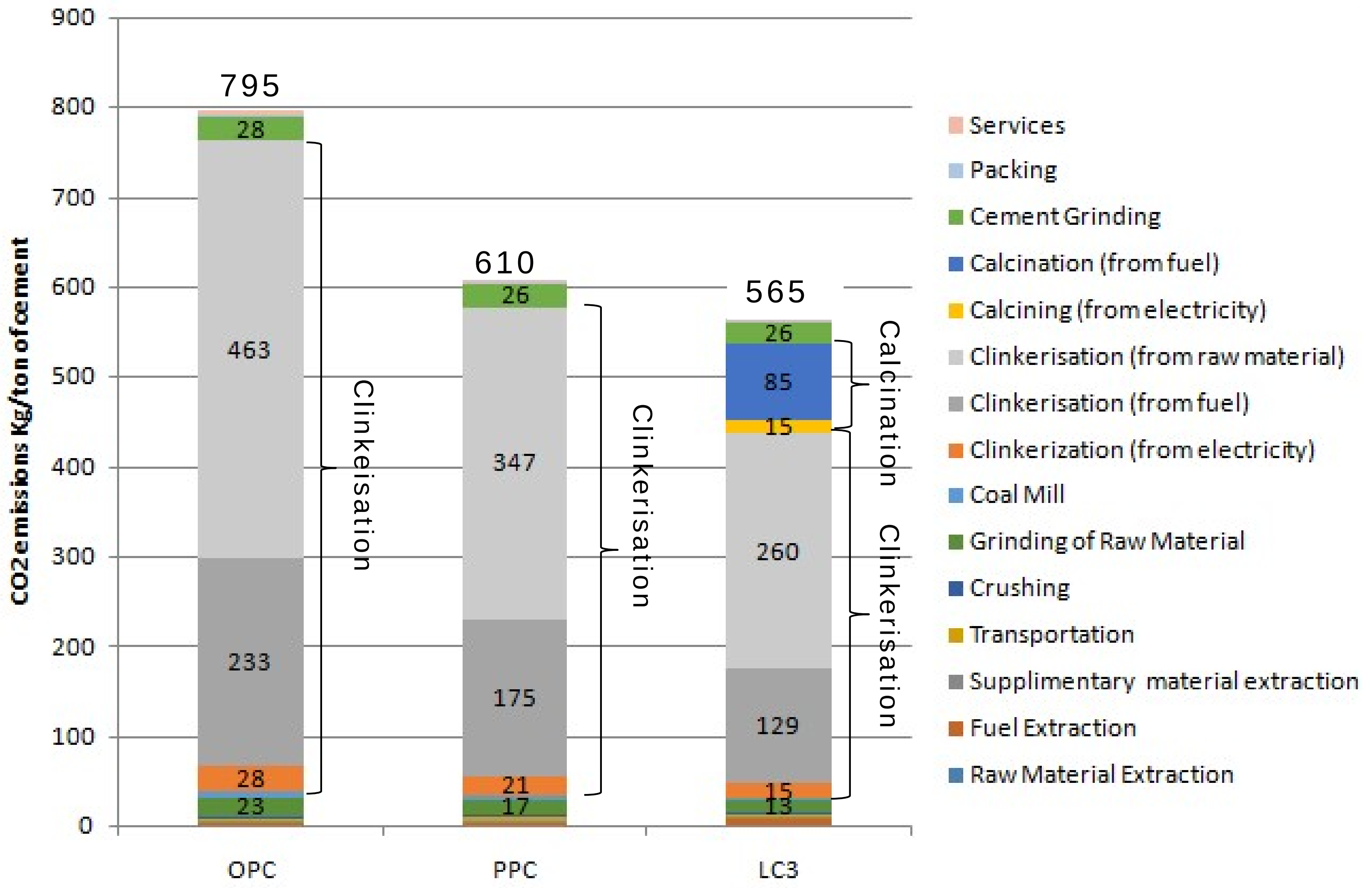
LC3 Energy Consumption (MJ/ton of Cement)



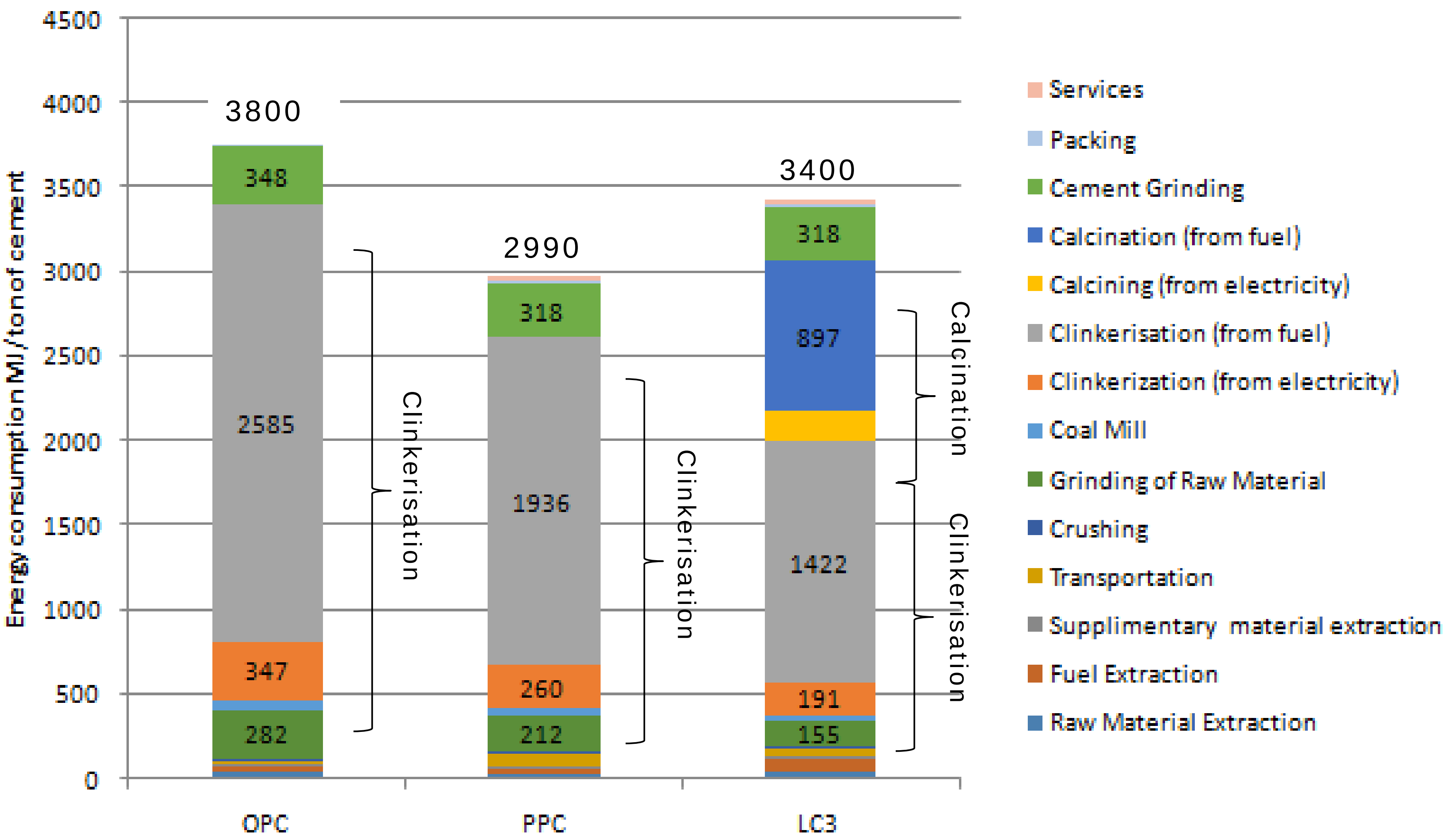
Total Energy Consumption:
3430 MJ/ton of Cement

Limestone Calcined Clay Cement LC3

Processwise CO_2 emissions



Processwise energy consumption



Limestone Calcined Clay Cement LC3

Cements: Gate-to-Gate Calculations

- Emissions and energy consumption during extraction of limestone, and transportation of limestone, clay, fly ash and gypsum are attributed to the cement production
- Emissions and energy related to extraction of clay, and the extraction and transportation of fossil fuels, and production of electricity are excluded.
- *Provides data for more reliable comparisons*
- *Avoids assumptions that are not relevant to local conditions and materials.*

Impact	OPC	PPC	LC^3
Energy consumed (MJ/ton of cement)	**3740**	**2860**	**3280**
Emission of CO_2 (kg/ton of cement)	**790**	**595**	**550**

Limestone Calcined Clay Cement LC^3

Work Planned

- Fine tuning of calcination energy for LC^3 as per Indian context.
- Visiting 6 more cement plants covering all geographical directions of India and conduct LCA to find out regional differences in CO_2 emissions and energy consumption by production of cement.
- Experimenting and addition of conversion factors for Indian context.
- Parametric studies with the models of the cement and concrete