(LC) embodied energy and GHG emissions of buildings

Status in Brazil

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SB13 Graz
SUSTAINABLE BUILDING CONFERENCE 2013
25.–28. SEPTEMBER 2013, TU GRAZ, AUSTRIA


BANCO CENTRAL DO BRASIL
REAL
DEUS SEJA LOUVADO
REAIS

40%

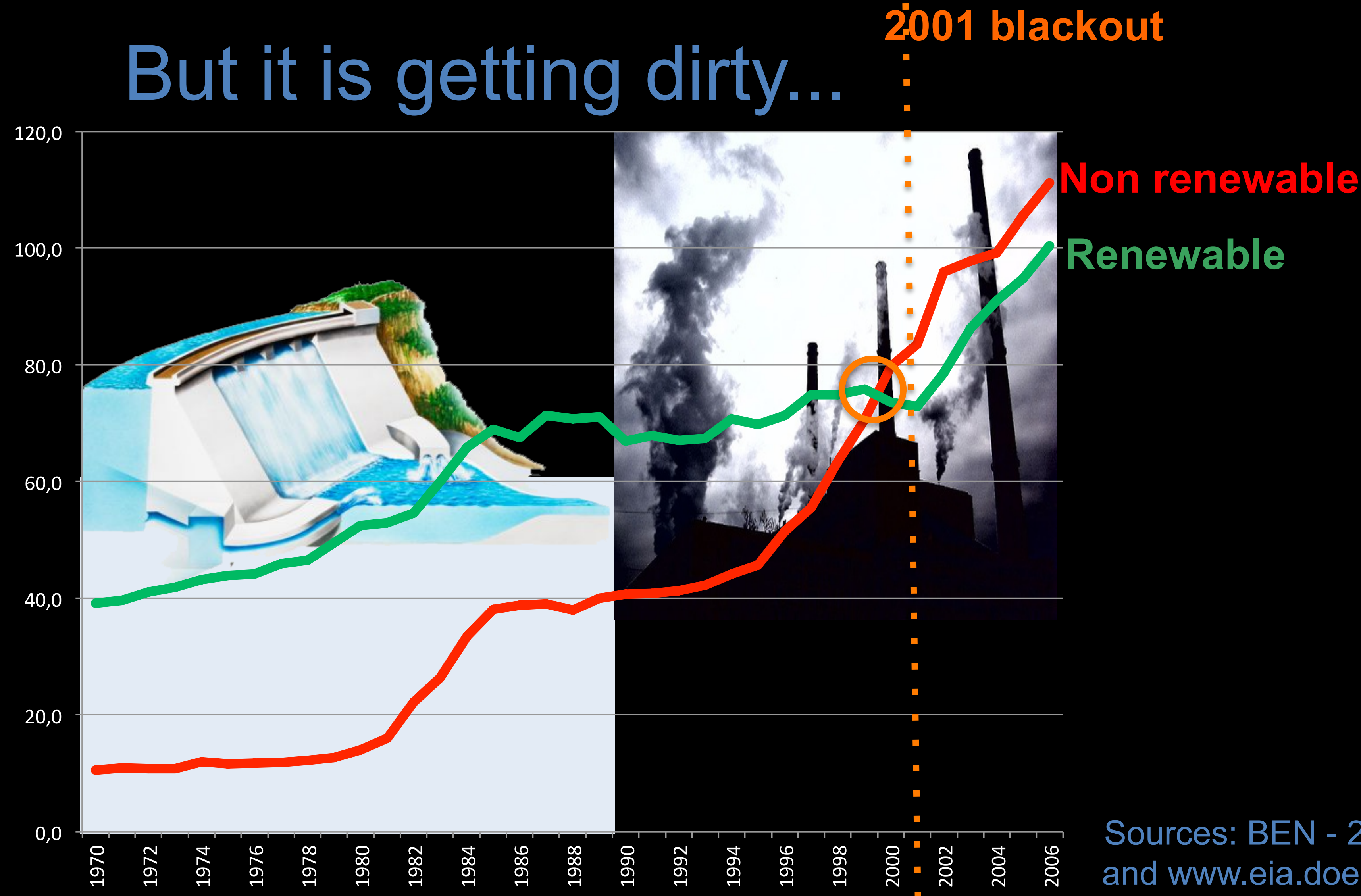
Fossil fuel emissions in LA

- Mexico and Brazil are key
  - Among the top 20 world emitters – 14th and 17th *
  - Brazil emissions per capita < 50% of the world average
- Share the same issues and challenges
  - Liquid fossil fuels respond for ~60-70% of GHG
  - ~10-14% coal
  - Still << world average
- Built environment is considered as strategic, but not priority

Data from Energy Information Agency (Department of Energy), 2008

Brazil

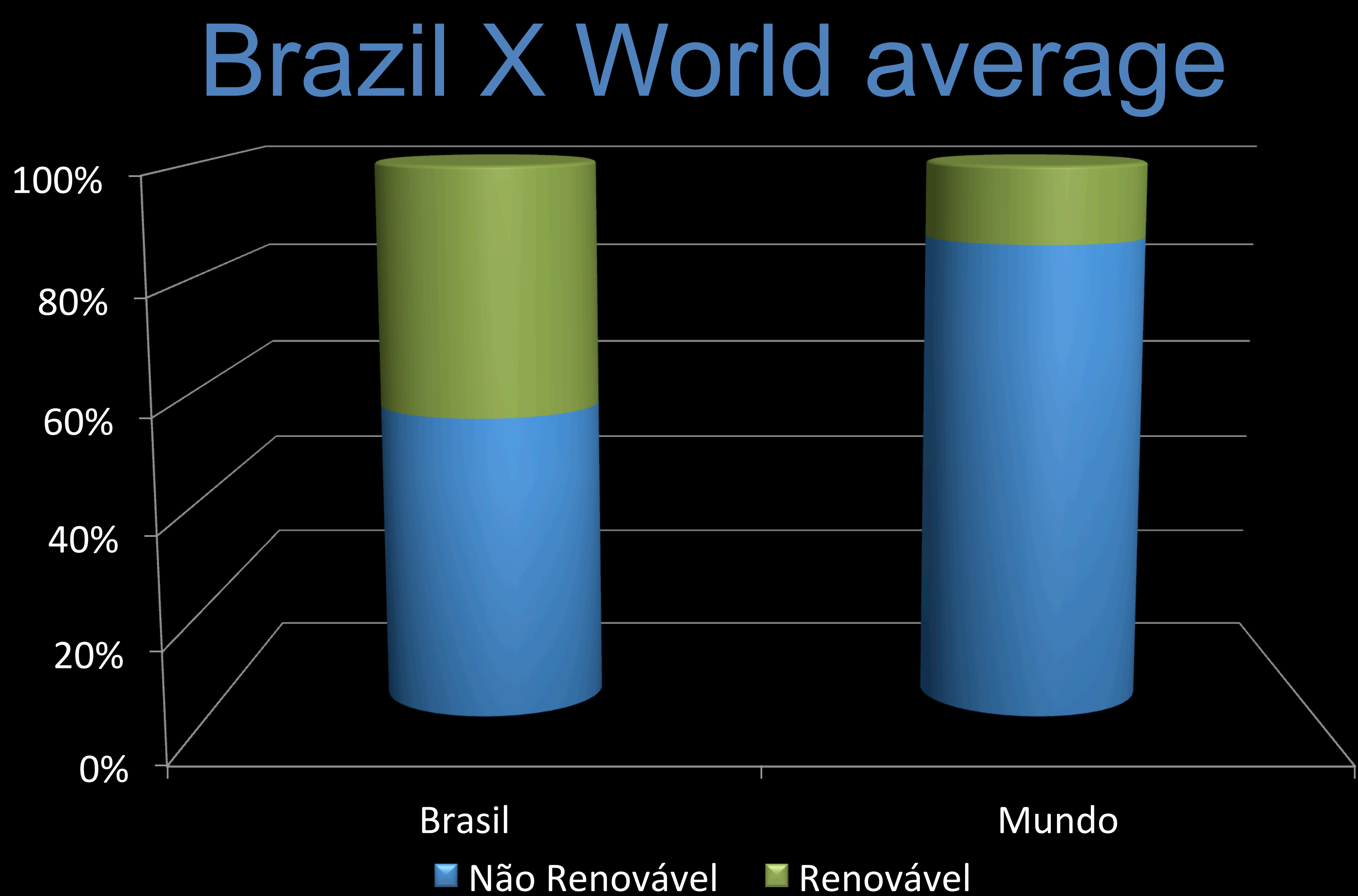
But it is getting dirty...



Sources: BEN - 2007
and www.eia.doe.gov

Roberto Lamberts, LABeee/UFSC. The challenge of "Zero Net Energy" buildings. SBCS 08 –2008

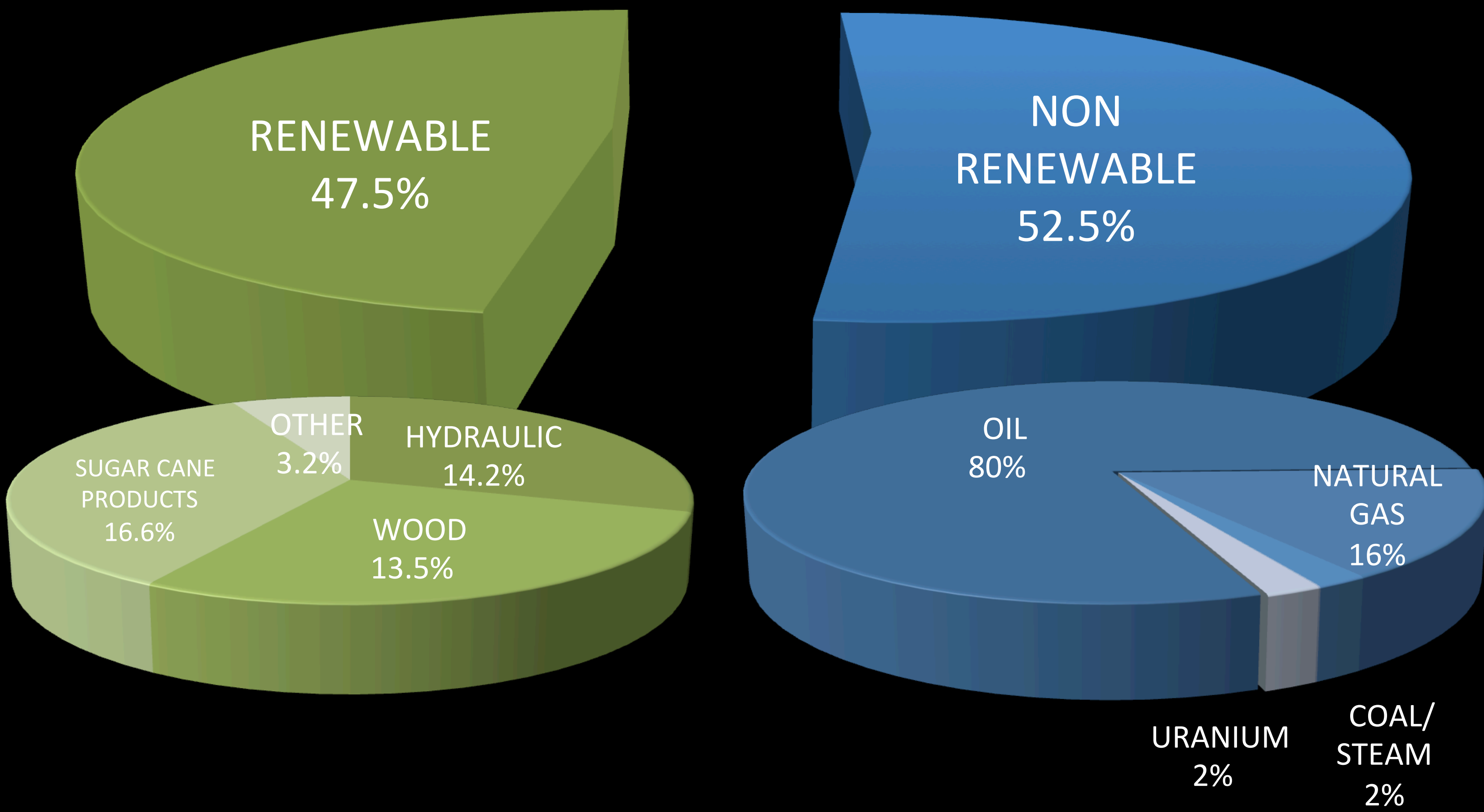
Energy matrix



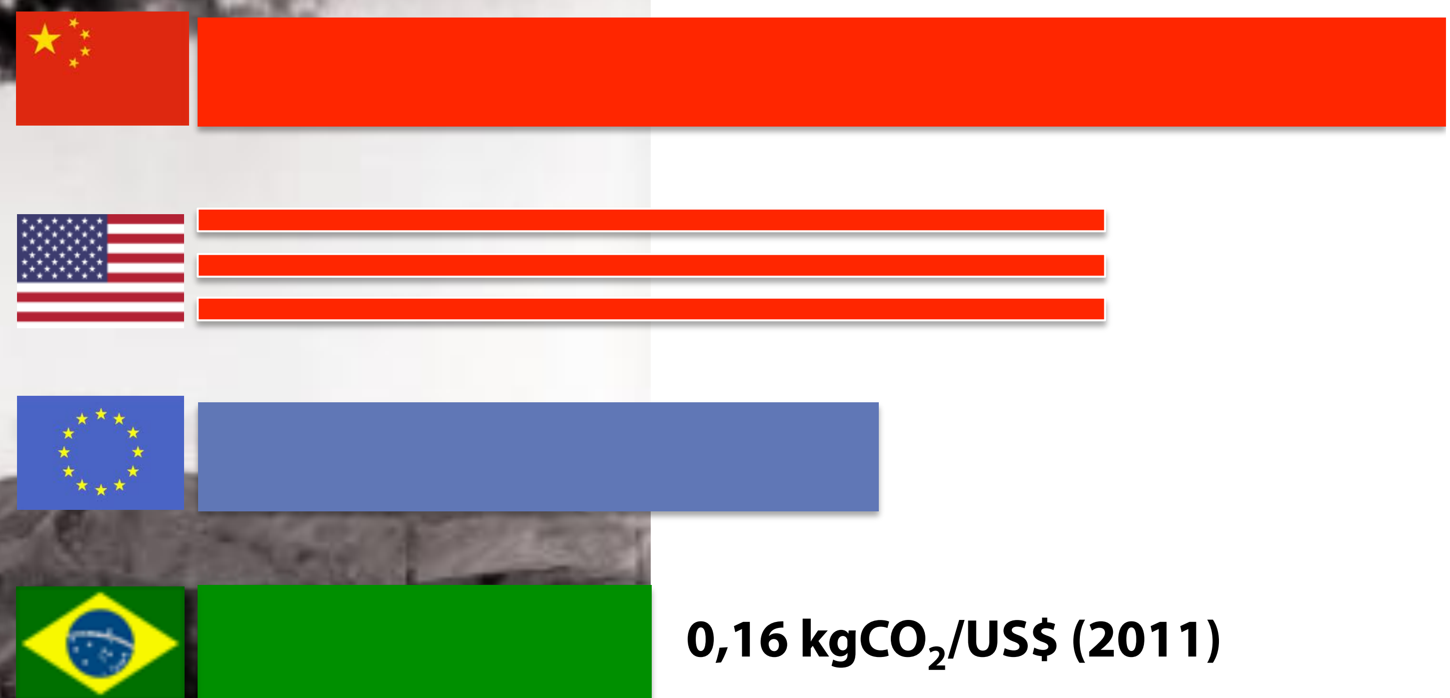
Roberto Lamberts, LABeee/UFSC. The challenge of “Zero Net Energy” buildings. SBCS 08 –2008

Brazil

Clean energy matrix...

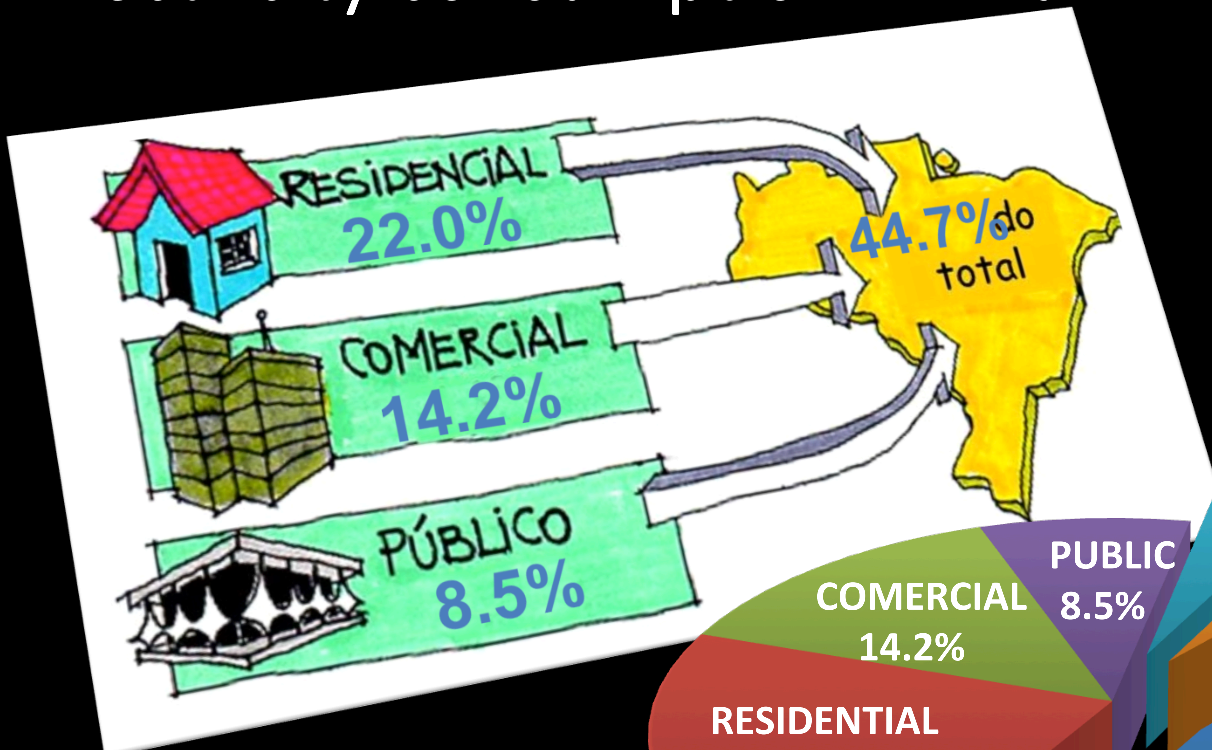


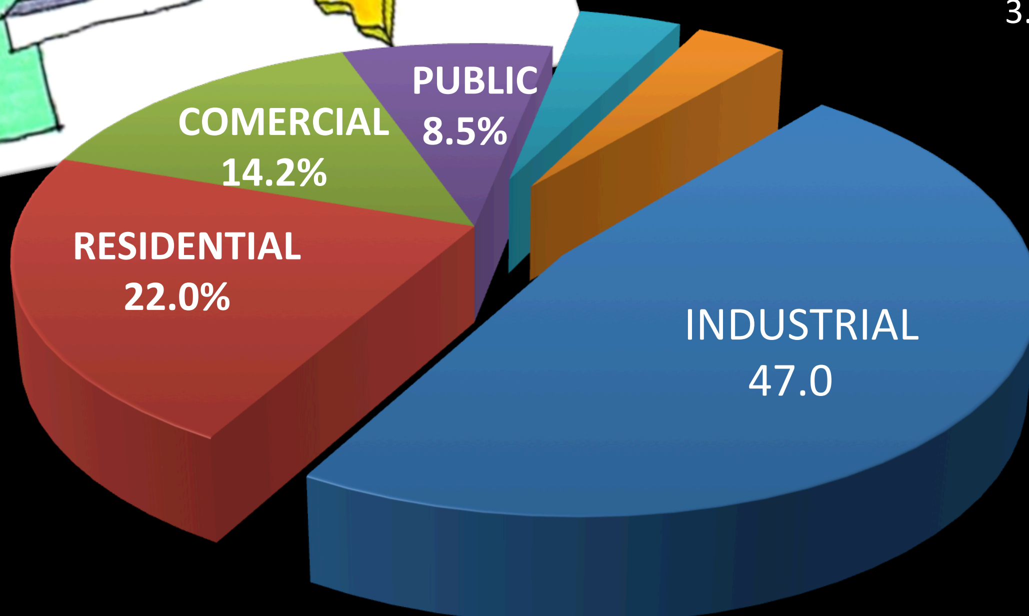
Carbon intensity in Brazilian economy



India, China, US and UK emitted respectively in 2010: 912, 766, 522 and 457g of CO_2 / kWh [Brazil - 87g of CO_2 per kWh]

Electricity consumption in Brazil

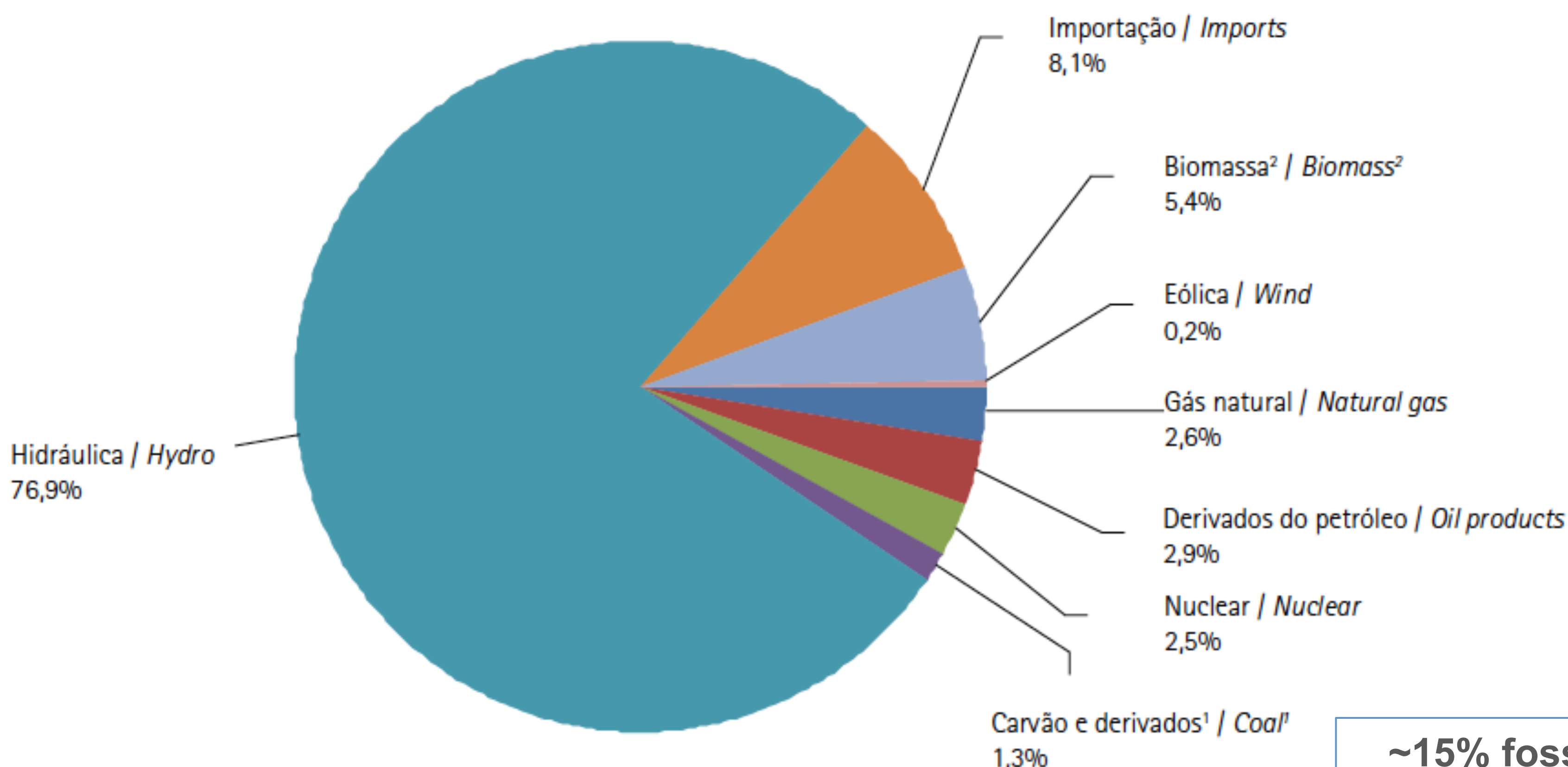




Source: BEN- 2007

Gráfico 1.1.1 | Oferta Interna de Energia Elétrica por Fonte – 2009

Chart 1.1.1 | Domestic Electricity Supply by Source – 2009



~15% fossil
2,5% nuclear
82% renewable

Notas/ Notes:
1 Inclui gás de coqueria / Includes coke gas.
2 Biomassa inclui lenha, bagaço de cana, lixívia e outras recuperações / Biomass includes firewood, sugar cane bagasse, black liquor e other wastes.

Brazilian context on CO_2 & Energy in buildings

- residential buildings in 2010
  - Brazil: 15.5 million tones of CO_2, from fuel combustion (mainly firewood and LPG for cooking)
  - USA: 321.7 | China: 303.1 | UK: 82.4 | India 74.8 (IEA, 2011)

60%

10%

2%

Brazilian $CO_{2(e)}$, Energy and LC database context

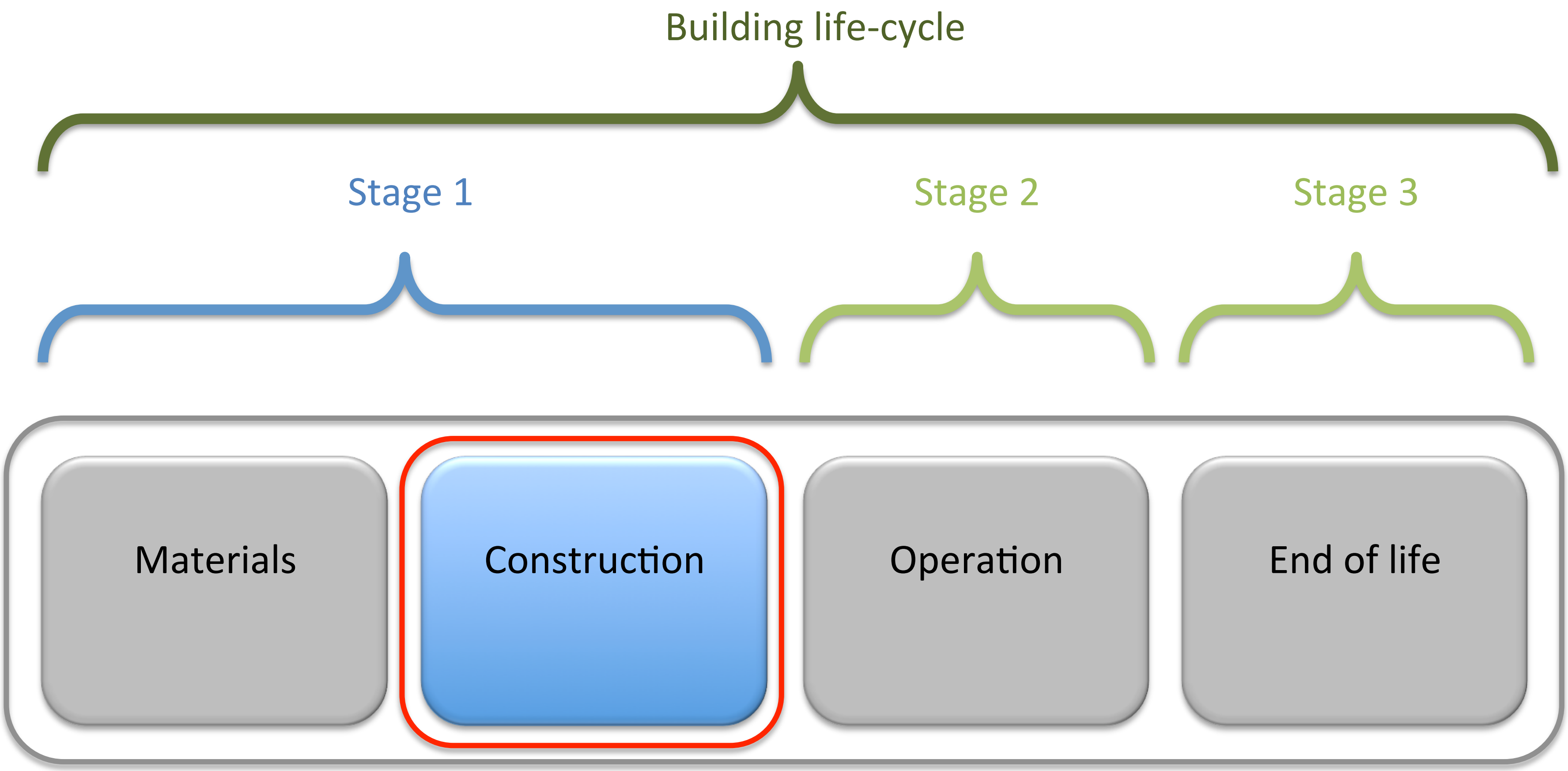
- I-O matrix not detailed enough
- NO national LCI, EE, EC/ECe databases

- IBICT LC initiative, connected to Ministry C&T
- In the construction sector
- Sub-sectoral initiatives
  - LCA of ceramic vs concrete components (roof tiles and masonry blocks)
- Academic initiatives

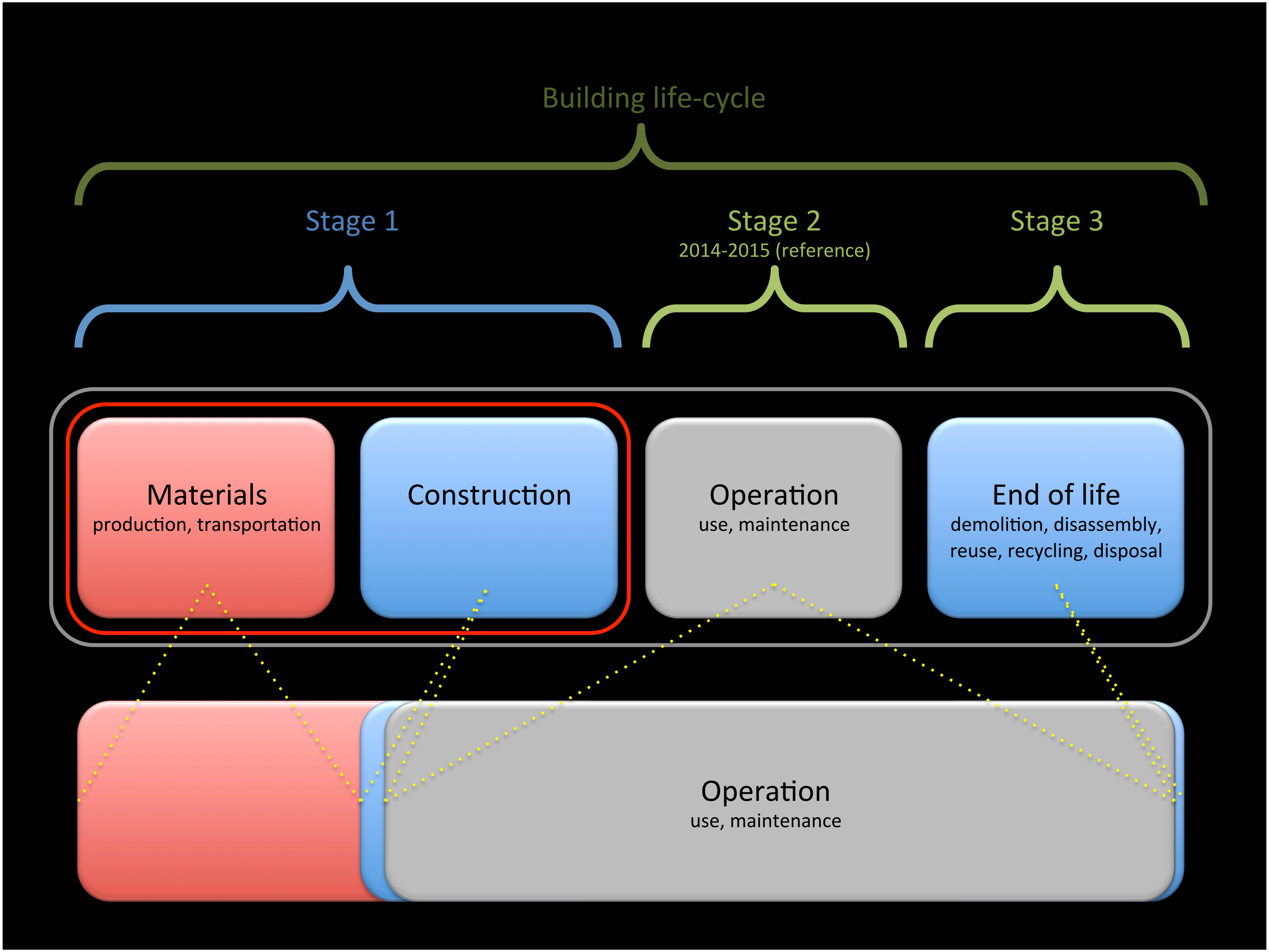
Life Cycle Assessment

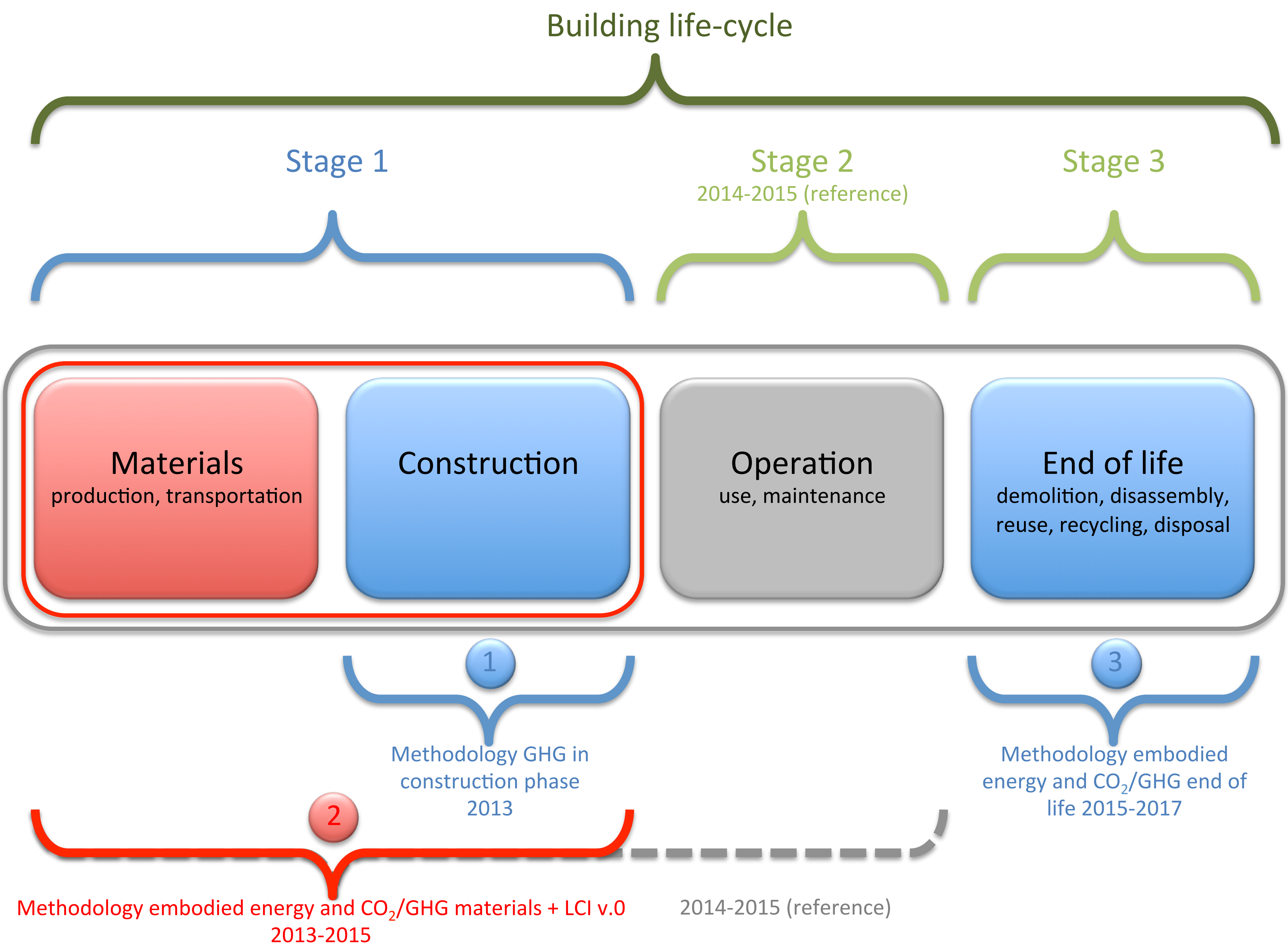
Issues of using foreign LCA data

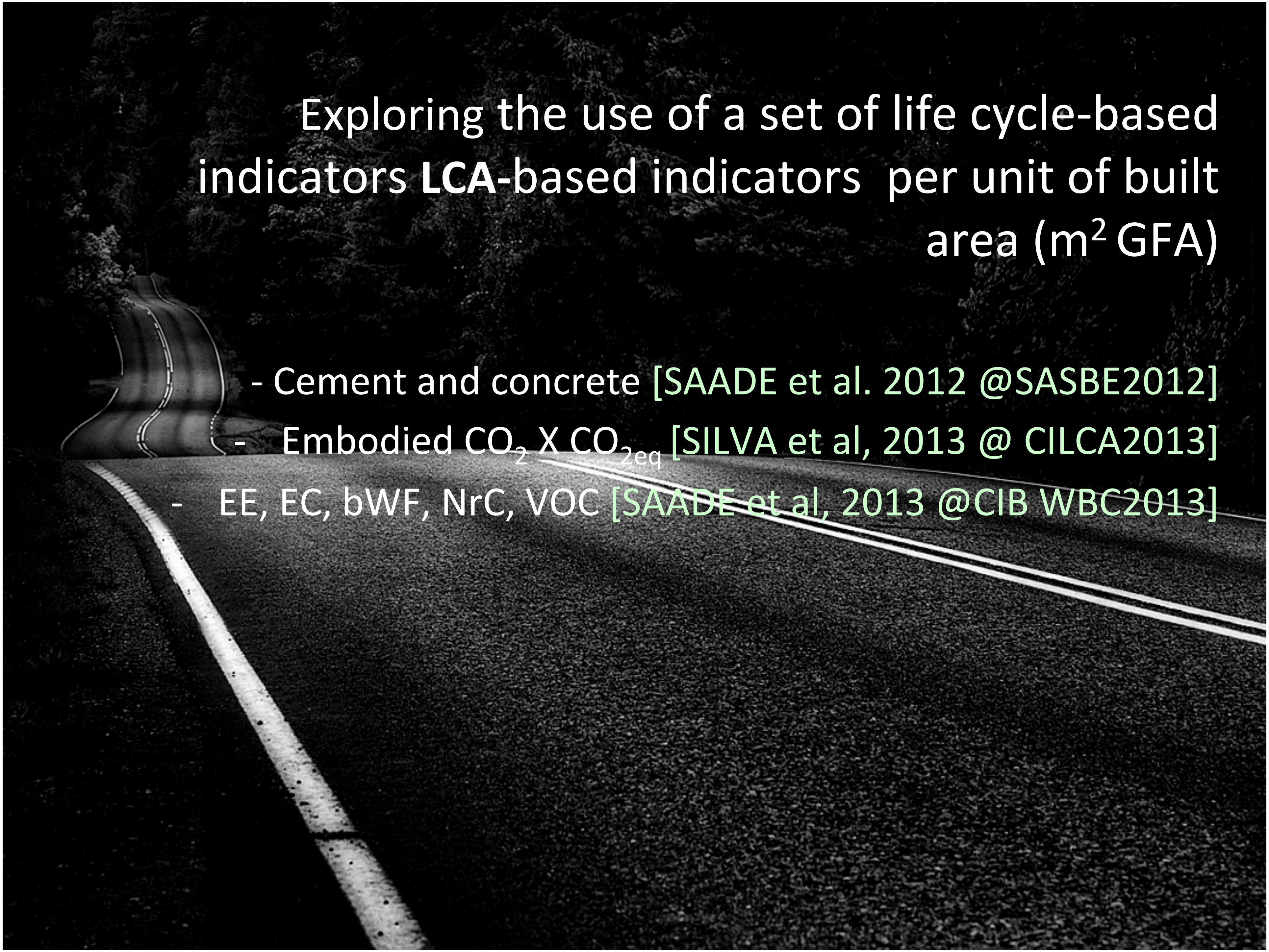
Evolution on kg CO_2 released/kg cement produced in different regions
(from Humphreys, Mahasenan, 2002)



138 (prefab) – 173 (conventional) kg CO_{2e}/m^2 GFA*
(70 buildings; 1.800.000 m^2 GFA)


Building life-cycle
Stage 1
Stage 2
2014-2015 (reference)
Stage 3
Materials
production, transportation
Construction
Operation
use, maintenance
End of life
demolition, disassembly,
reuse, recycling, disposal
Operation
use, maintenance

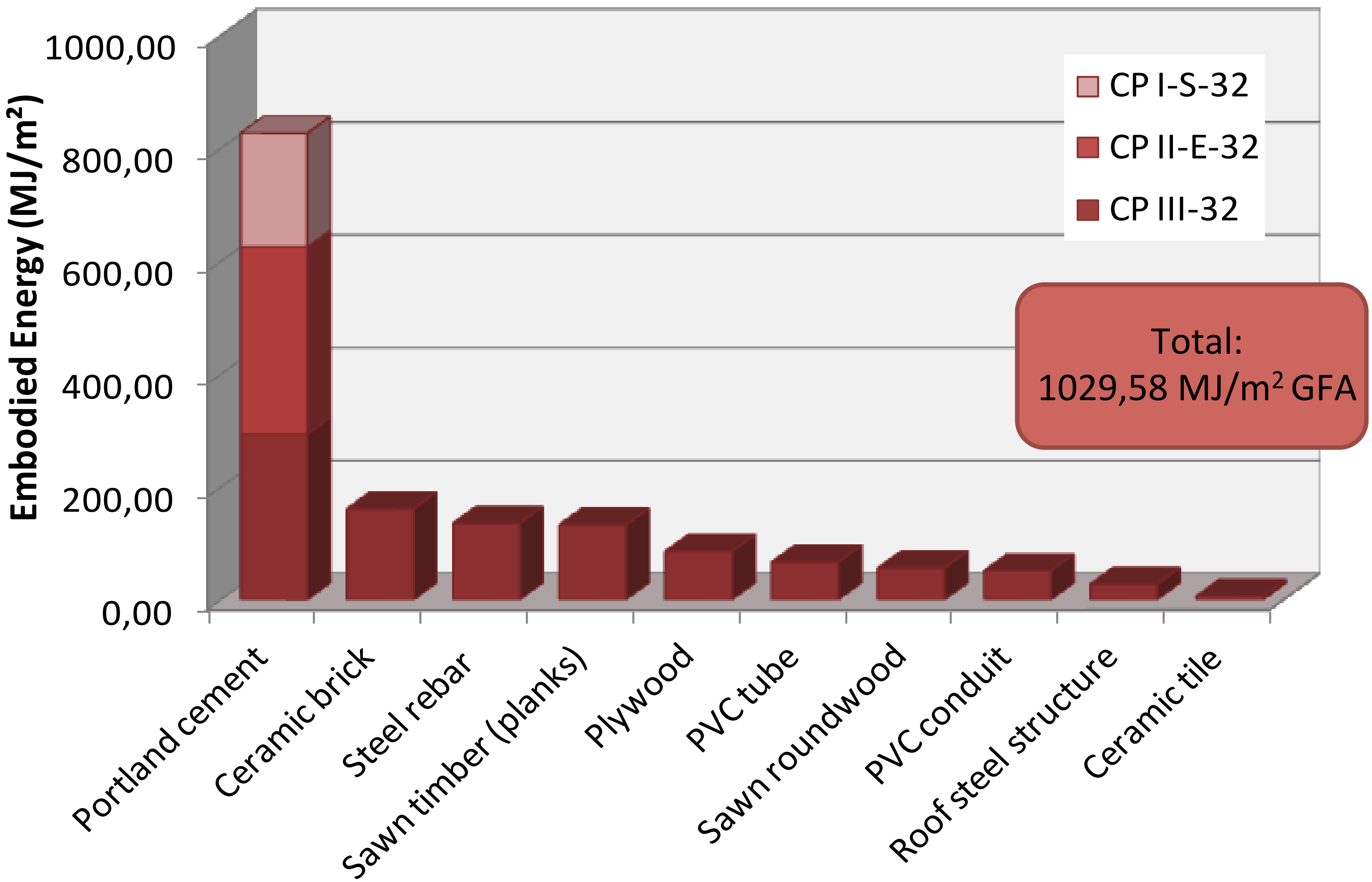

Building life-cycle
Stage 1
Stage 2
2014-2015 (reference)
Stage 3
Materials
production, transportation
Construction
Operation
use, maintenance
End of life
demolition, disassembly, reuse, recycling, disposal
1
Methodology GHG in construction phase 2013
3
Methodology embodied energy and CO_2/GHG end of life 2015-2017
2
Methodology embodied energy and CO_2/GHG materials + LCI v.0 2013-2015
2014-2015 (reference)


Exploring the use of a set of life cycle-based indicators **LCA**-based indicators per unit of built area (m^2 GFA)
- Cement and concrete [SAADE et al. 2012 @SASBE2012]
- Embodied CO_2 X CO_{2eq} [SILVA et al, 2013 @ CILCA2013]
- EE, EC, bWF, NrC, VOC [SAADE et al, 2013 @CIB WBC2013]

Approach [SILVA et al, 2013 @ CILCA2013]

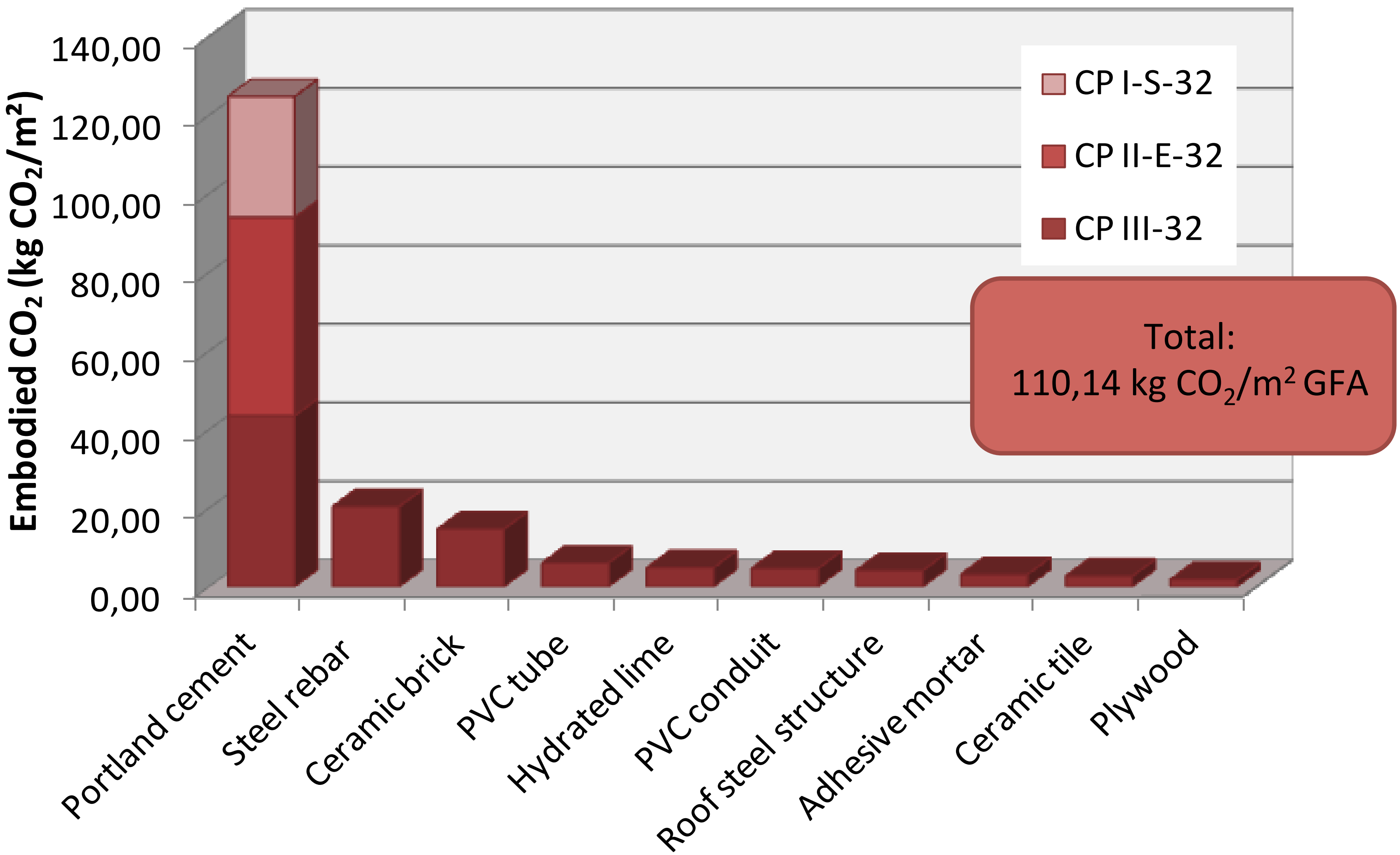
Building materials and components	Functional unit	Data input	Data source
Ready-mixed Concrete (fck 30)	1 m^3	Sand, gravel, water and cement (CP I-S-32, CP II-E-32 or CP III-32)	Silva, 2006
Portland Cement (CP I-S-32, CPII-E-32 and CPIII-32)	1ton	Calcium sulfate, clinker and crushed blast furnace slag	Silva, 2006
Steel rebar, Roofing steel structure, Copper wire	1ton	ELCD processes, adjusted to Brazilian energy mix	ELCD, version 2.0
PVC (conduit, tube)	1ton	Industry Data process, adjusted to Brazilian energy mix	Industry Data, version2.0
Wood (plywood; dry plank; dry roundwood)	1 m^3	Ecoinvent processes, adjusted to Brazilian energy mix	Ecoinvent, version 2.2
Sand, Gravel, Acrylic paint, Hydrated lime, Adhesive mortar, Ceramic tile, Glass	1ton	Ecoinvent processes, adjusted to Brazilian energy mix	Ecoinvent, version 2.2
Ceramic brick	1ton	Manfredini; Sattler (2005, EE); Hammond; Jones (2011, EC)	

Results: Embodied Energy



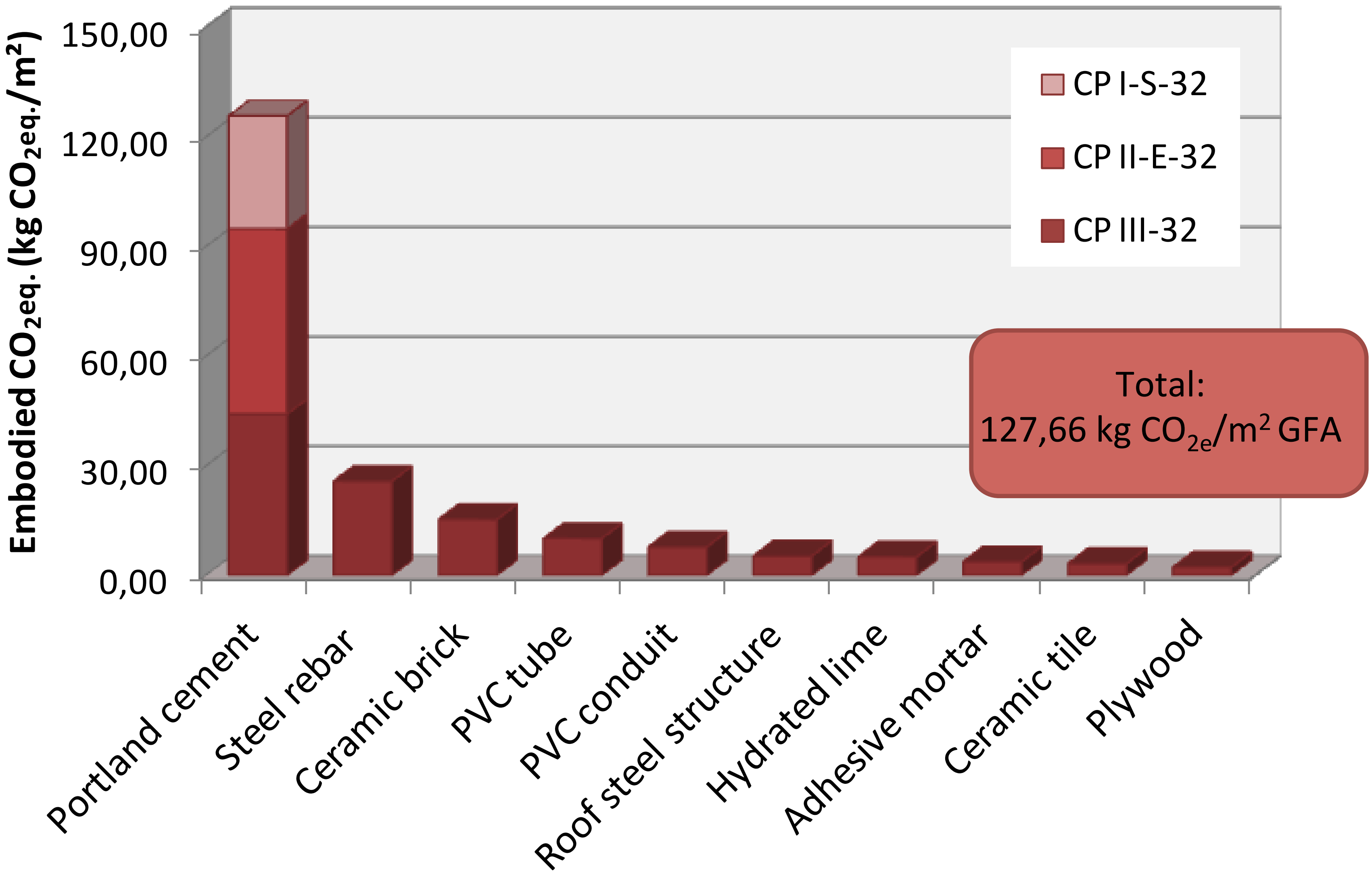
[SILVA et al, 2013 @ CILCA2013]

Results: Embodied CO_2



[SILVA et al, 2013 @ CILCA2013]

Results: Embodied CO_{2e}



[SILVA et al, 2013 @ CILCA2013]

Results

Material/component		Embodied Energy (MJ/m² GFA)	Embodied CO_2 (kg CO_2/m² GFA)	Embodied CO_{2e} (kg CO_{2e}/m² GFA)
Portland Cement (total)	***CP III-32***	294,13	43,53	44,17 1/3
Sand		0,01	0,00	0,00
Gravel		0,03	0,00	0,01
Steel rebar		135,78	20,45	25,82
Roof steel structure		28,08	4,18	5,34
Ceramic brick		161,24	14,70	15,33
Ceramic roof tile		0,01	0,00	0,00
Sawn timber plank		132,91	0,82	1,03
Sawn roundwood		56,76	0,26	0,32
Plywood		86,25	1,85	2,30

[SILVA et al, 2013 @ CILCA2013]

Results (cont'd)

Material/component	Embodied Energy (MJ/m^2)	Embodied CO_2 ($kg\ CO_2/m^2$)	Embodied CO_{2e} ($kg\ CO_{2e}/m^2$)
PVC tube	67,23	6,10	10,15
PVC Conduit	51,80	4,70	7,82
Adhesive Mortar	3,13	3,19	3,78
Hydrated lime	1,58	4,87	5,11
Ceramic tile	6,85	2,73	3,28
Copper wire	1,15	0,08	0,10
Acrylic paint	1,12	0,83	1,02
PVA paint	0,45	0,34	0,41
Glass	1,07	1,50	1,64
Accounted total/m² GFA	1029,58	110,14	127,66

~16%

[SILVA et al, 2013 @ CILCA2013]

✓Portland cement CP III-32, ceramic brick, steel rebar, sawn timber planks, plywood, PVC tube and conduit respond for 90,3% of total embodied energy and 83,5% of embodied $CO_{2e.}$

Cement, ceramic brick, hydrated lime: **above 95%**

Plywood, roundwood, sand, ceramic tile, adhesive mortar: **80%-95%**

Steel rebar, PVC tube, PVC conduit, gravel, roof steel structure: **60%-80%**

✓Adopting embodied CO_2 for all building materials and components, as a rule of thumb descriptor of climate change impact, can mislead conclusions.

[SILVA et al, 2013 @ CILCA2013]

Results

	EE (MJ/m^2)	EC_{eq} ($kgCO_{2eq}/m^2$)	EC (kg/m^2)	bWF (m^3/m^2)	NRc (kg/m^2)	VOCe (kg/m^2)
CP I-S-32	924.00	139.37	140.54	0.12	470.59	4.85E-4
CP II-E-32	702.49 (-23.97%)	105.57 (-24.25%)	106.59 (-24.16%)	0.70 (+82.26%)	358.15 (-23.89%)	4.21E-4 (-13.15%)
CP III-32	329.79 (-64.31%)	48.81 (-64.98%)	49.53 (-64.76%)	1.50 (+91.77%)	168.88 (-64.11%)	3.00E-4 (-38.13%)

	EE (MJ/m^2)	EC_{eq} ($kgCO_{2eq}/m^2$)	EC (kg/m^2)	bWF (m^3/m^2)	NRc (kg/m^2)	VOCe (kg/m^2)
Concrete w/ CP I-S-32	330.41	49.95	50.84	0.82	695.78	1.85E-3
Concrete w/ CP II-E-32	271.02 (-17.97%)	40.85 (-18.22%)	41.68 (-18.01%)	1.00 (+18.36%)	638.94 (-8.17%)	1.74E-3 (-5.57%)
Concrete w/ CP III-32	131.12 (-60.32%)	19.55 (-60.85%)	20.28 (-60.11%)	1.30 (+37.10%)	576.26 (-17.18%)	1.72E-3 (-6.69%)

[SAADE et al, 2013 – CIB WBC2013]

Remarks

✓EE of 1.030 MJ/m^2 and ECO2e of 128 kg CO_{2e}/m^2

✓Top 6 EE (**Portland cement CP III-32, ceramic brick, steel rebar, sawn timber planks, plywood and PVC tube**) respond for > 80%
✓>80% of the accounted embodied CO_{2e} - **cement, steel rebar, ceramic brick and PVC tube and conduit**.

✓A core database encompassing **7** materials and components provides a reasonable description of the embodied energy (>90%) and CO_{2e} (>83%) profiles. Broadening the database to encompass **12** items allows a very accurate description **(>97%)**

[SILVA et al, 2013 @CILCA2013] [GOMES et al, 2013 @SB13Munich]

Remarks

- ✓ This describes a number of buildings of **a certain typology**
- ✓ Ranking and materials may change
- ✓ Next research steps: database expansion to include other building typologies (SINDUSCON-SP); comparison embodied x operational energy
- ✓ Evolve to gradually constitute an LCI database to enable the use of proposed metrics, and LCA methodology as decision-making tools.

Indicators to Support Sustainability and Performance-Based Selection of Structural Frame Alternatives in Concrete: Preliminary Validation at Element Level

Flavia R. M. Oliveira | Maristela G. da Silva | Vanessa Gomes

- EE, CF/GWP, bWF, NRc, Mc

Method and approach

DQI Functional unit and inventory data sources

Construction materials and components	Functional unit	Data source
Concrete (fck 30MPa) [a]	1 m^3	Silva, 2006
Portland cement (CPIII-32) [a]	1 ton	Silva, 2006
Steel rebar (reinforcing steel)	1 ton	ELCD (European life cycle database)
Plywood formwork, Sand, Gravel	1 m^3	Ecoinvent
Wire Rods (prestressing steel)	1 ton	WorldSteel Association

[a] Concrete mix with cement type CPIII-32 (66% of ggbs as clinker replacement in cement)

Method and approach

1- Span over height ratio (ℓ/d), [m/m]

2- Applied stress over ultimate strength ratio *(for columns)*, fc / fck [kN/m^2 / kN/m^2]

3- Column density*:* gross floor area over number of columns (m^2 GFA/nr), [m^2]

4- Beam over slab height ratio, [m/m]

5- Reuse Potential*:* [% volume able to be disassembled]

functional indicators

safety, durability and adaptability requirements

Method and approach

environmental indicators

ISO/TS 21929-1:2006
ISO 21931-1:2010
methodological guidelines

1- Carbon Footprint [$kgCO_{2-eq}$/f.u.]

2- Embodied Energy [MJ/f.u.]

3- Blue Water Footprint [m^3/f.u.]

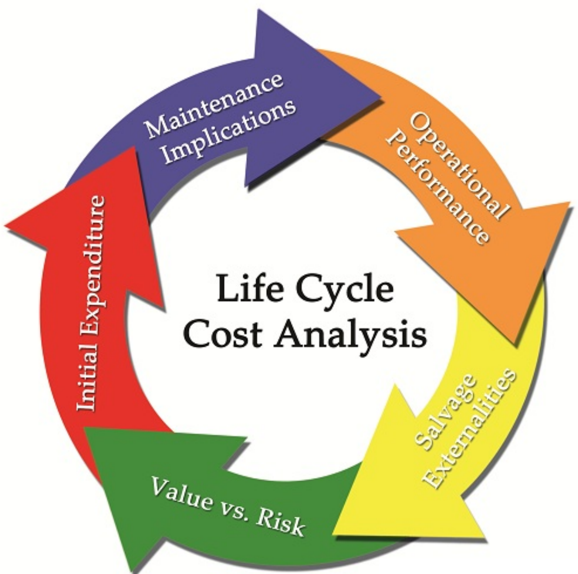
4- Materials resource consumption [kg/f.u.]
(steel + concrete+ plywood formwork)

5- Non renewable content – NRc (ADP*)
[$(kg_{tot\ abiotic\ mat} - kg_{recycled} - kg_{reused})$ / f.u.]

resource intensity, climate change

Method and approach

economic indicators



1- Life cycle costs (LCC) [$/functional unit]

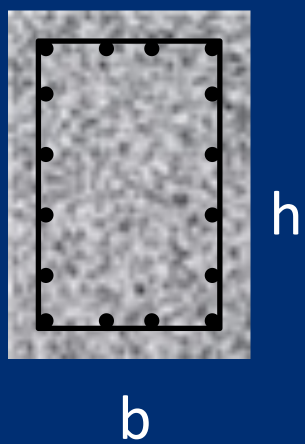
investment + maintenance + end of life (demolition/disassembly, recycling, reuse, final disposal…) costs

2- Payback period*:* [years]

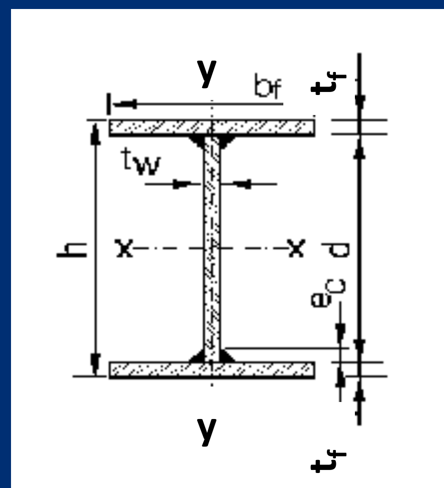
3- Local economy support: [% cost] of local (extracted or fabricated within a 300 km-radius) materials/products

monetary flows

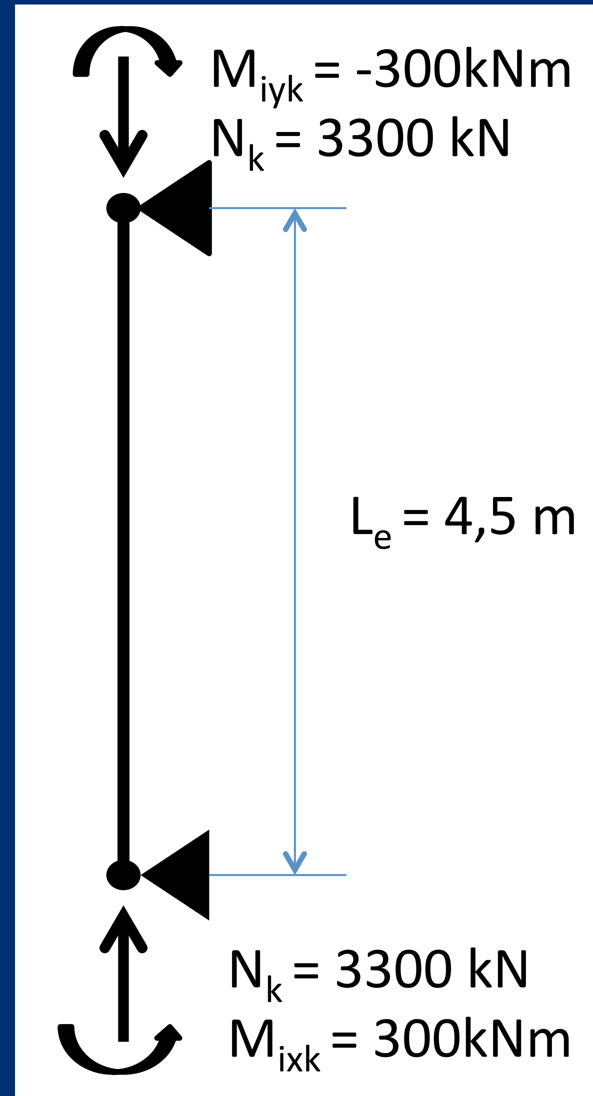
Case Study presentation



a) Concrete cross section



b) Steel cross section



c) Axial force and initial *end moments*

Obs.

1. Nominal cover (design depth of reinforcement cover of concrete column) of 4.0 cm (exposure conditions class III from ABNT NBR 6118:2007 corresponds to a marine and industrial environment;
2. The software STRAP Metal from PINI WEB© was used for steel column design.

sb13 munich
Implementing Sustainability - Barriers and Chances

Results and discussion

sb13 munich
Implementing Sustainability - Barriers and Chances

Estimated service lives, initial (capital) costs, repair costs and life cycle costs for the case study

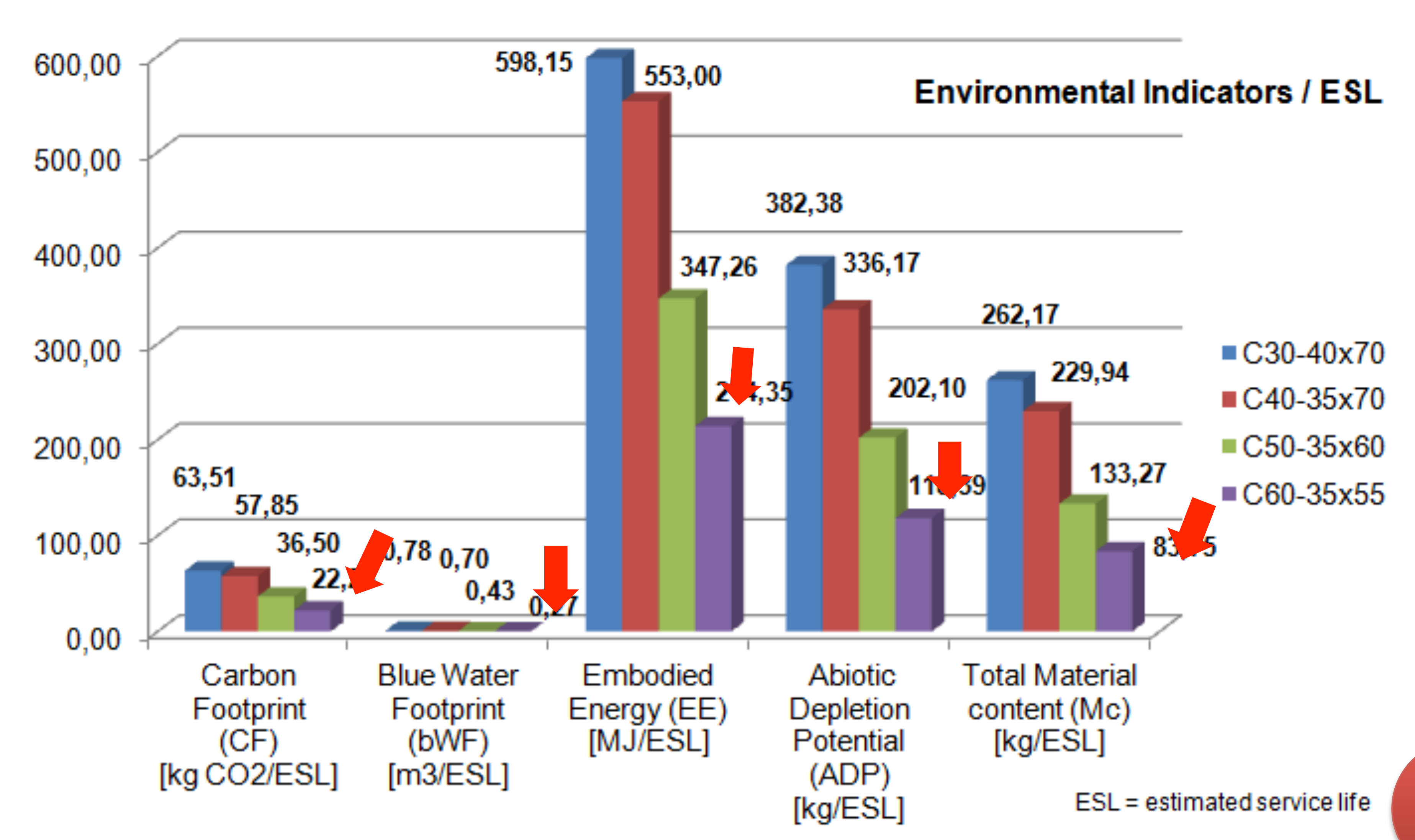
22.2%

45.0%

	Service life study					
				LCC [US$]		
Reinforced Concrete column alternatives	Characteristic strength fck [MPa]	Concrete cross section, b x h [cm x cm]	Estimated Service life [years]	Initial costs	Maintenance / repair costs	Life cycle costs (LCC)
	C30	40 x 70	17.1	658	578	1237
	C40	35 x 70	17.1	597	614	1211
	C50	35 x 60	23.9	589	384	973
	C60	35 x 55	31.5	512	172	684
Structural Steel column alternatives	Steel type	Steel section [mm x mm]				
	MR-250	CS 650X330	-	2042	-	$\boxed{2042}$
	AR-345	CS 550X279	-	1726	-	$\boxed{1726}$

[OLIVEIRA et al, 2013 @ SB13Munich]

Results and discussion



[OLIVEIRA et al, 2013 @ SB13Munich]

Indicators to Support Sustainability and Performance - Based Selection of Structural Frame Alternatives in Concrete: Validation at Typical Floor and Superstructure Levels

Flavia R. M. Oliveira | Maristela G. da Silva | Vanessa Gomes

- EE (EEr+EEnr), CF/GWP, bWF, NRc, Mc + [AP, ODP, EP, PCOP]

SB13 Graz
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Method and approach

Three case studies, residential (+28)

Case study 1: 27.5 cm-thick **reinforced concrete waffle slabs with beams**

Case studies 2 and 3: 18.0 cm-thick **prestressed flat slabs**

Fck (MPa)	Cement CP III-32 (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water (l//m^3)
30	380	874	950	190

1

3

2

Results and Discussion

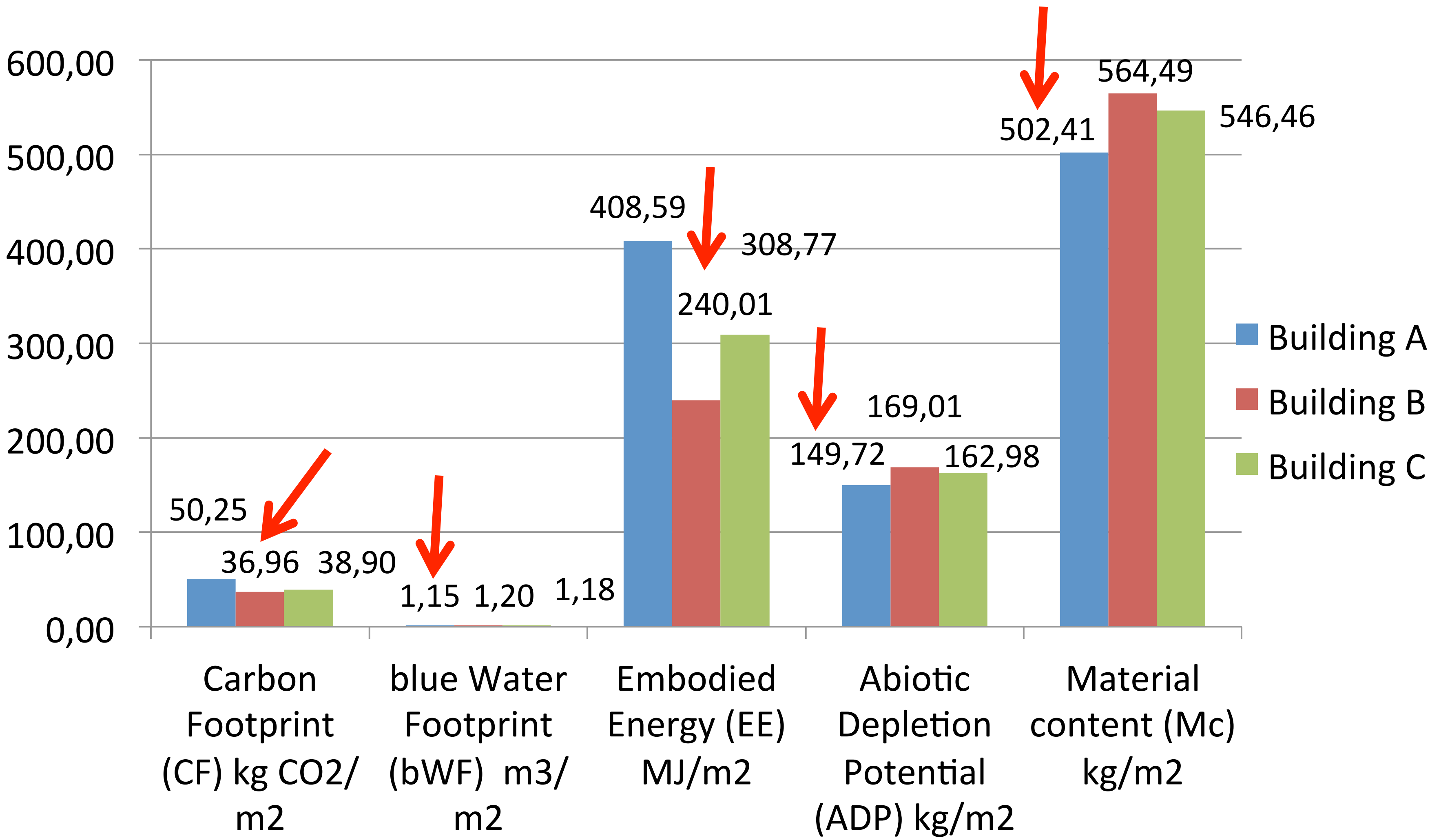
Case studies	Typical floor description	Estimated Service life [years]	Life cycle costs (LCC) US $ /m$^2_{structural\ floor\ area}$						
			Initial costs					Maintenance / Repair costs	Total life cycle costs
			Plywood formwork	Concrete	Rebar	Prestressing steel	Total initial costs		
1	RC waffle slab	11.7	2.93	17.48	20.07	0.00	40.47	57.85	98.32
2	PC flat slab	11.2	2.94	20.00	9.44	6.73	39.10	57.85	96.95
3	PC flat slab	11.2	2.79	19.33	8.53	5.36	36.00	57.85	93.85

Indicator	Typical floor		
	Case study 1	Case study 2	Case study 3
Local economy support [% in costs]	48	56	59

longer spans

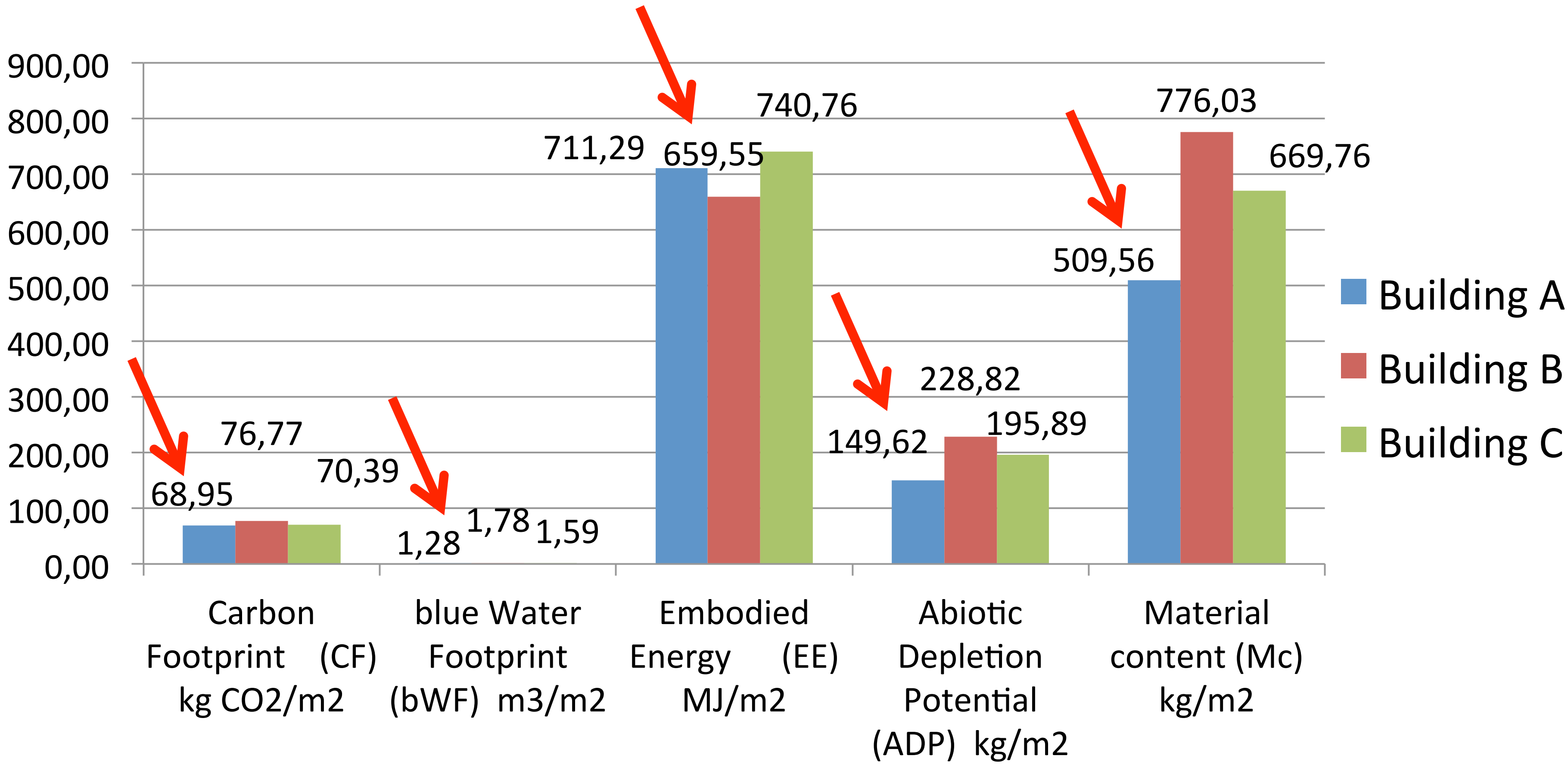
Results and Discussion

Environmental indicators per unit of structural area (typical building floor)



Results and Discussion

Environmental indicators per unit of structural area (superstructure)



Final remarks

- **Complexity and confusion of** language, tools, methodologies and metrics/aggregation: CO_2 x CO_{2e}, CF…; m^2 built x delivered
- Common approach
- Need of **leadership** to advance: targets, means and plans
  - Primary leadership from the government due to market failures and because emission reduction plans need to reach each fiber of the built environment
  - Local authorities – lock/unlock private action
    - **Sectorial leadership** – practical response
    - Each layer of the **value chain**
- Public-private partnerships to **delineate transition plans** into low carbon emission activities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Vielen Dank!