



Sustainability Assessment Of A Public Housing In Hong Kong – Combined LCA And LCC Study And Further Application In A Guangzhou Mix-used Project

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Background

- HD proposed to develop a **combined LCA and LCC tool** to respond to -
 - Quality Housing Initiatives Recommendation 30 in 2000 for Quality Reform
 - Construction Industry Review Committee Recommendation 90 in 2001 to take lead in practicing **LCC**
- A consultant was commissioned in June 2002 to conduct the study

Global Trends

- Complement and enhance “Credit” based environmental assessment schemes (HK-BEAM, LEED, BREEAM, etc)
- ISO standards now in place (ISO 14040, 15686)
- *Life Cycle Costing* becoming more important, longer investment decisions (PFI etc)
- *Life Cycle Assessment* considered to be more suitable to determine environmental performance

Regional Trends

- **Industry needs numbers** and user-friendly ways to compare options and minor differences
- Value slowly becoming a determining factor
- **Better information / awareness** in the market
- Kyoto and other initiatives raising importance
- Trend towards **Corporate & Social Responsibility**



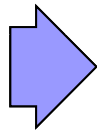
The Study

Study Objectives

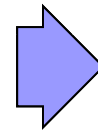
- Validate environmental friendliness / cost effectiveness of materials used in NH1 block from life cycle perspectives;
- To test architectural materials in the future
- To provide designers with a decision making tool



Construction



Occupation



Demolition

LCA Methodology

ISO Standards Series Environmental Management - Life Cycle Assessment

- ISO 14040 : Principles and Framework
- ISO 14041: Goal and Scope Definition and Inventory Analysis
- ISO 14042: Life Cycle Impact Assessment
- ISO 14043: Life Cycle Interpretation

LCA Data Sources & Principles

- LCA methodology
- LCA data sources
- Regionalisation
- Characterisation, Normalisation & Weighting
- Operational Model
- Repair and Maintenance Model
- Churn Model
- End of Life Model
- LCA results



The Model Developed

Computer Model

- Technical Structure (Software)
 - Windows Based for **Familiarity**
 - The Model has been optimised for **Speed**
 - Output / Results Provided in Excel Format for **Ease of Presentation**
 - Database can be expanded to cope with new functional units and materials
 - Base building is fixed to ensure consistency in results

Computer Model (Cont'd)

- Environmental Data
 - Presented in E-Points
 - **1 E-Point = 1 Hong Kong Person**
 - Database contained 'normalised' values for each material used in New Harmony 1 Block
 - Data adjusted to reflect HKHA situation and regional requirements
 - New data can be introduced for new materials
 - Currently 100 + materials in database

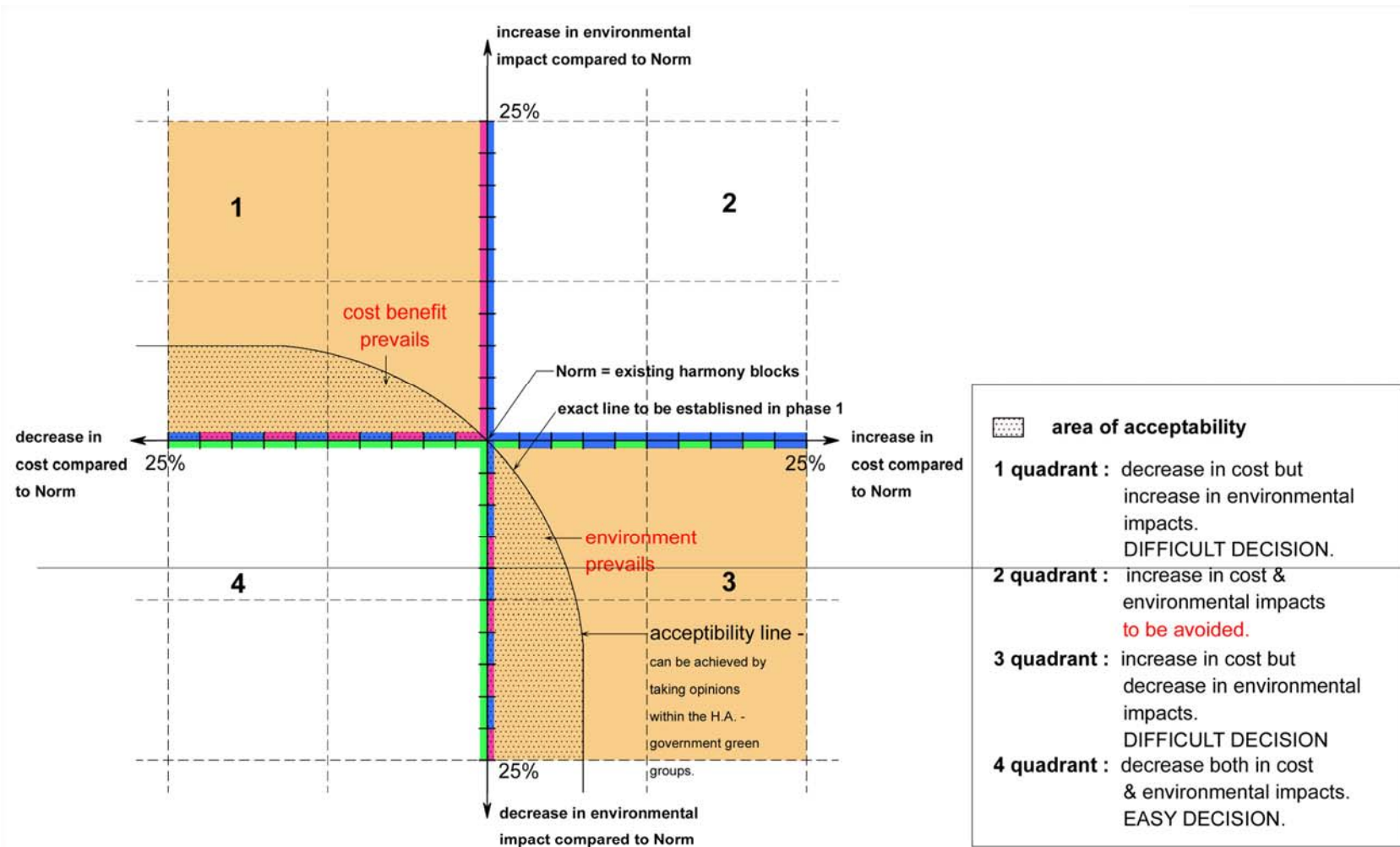
Computer Model (Cont'd)

- Cost Data
 - Established using current market prices
 - Ability to adjust rates using TPI formula
 - Currently rates expressed in HK\$/kg to reduce database size
 - Repair & Maintenance rates derived from recent DTC tenders
 - Operational Rates based upon latest CLP tariffs
 - Discount / Inflation Rates can be adjusted by users

Cost Model

- Based upon ISO 15686 – Whole Life Costing
- Spilt whole life cycle cost into stages
- Spilt cost into functional units
- Allows comparison of 3 stage costs/environmental impacts

LCA/LCC Resolution





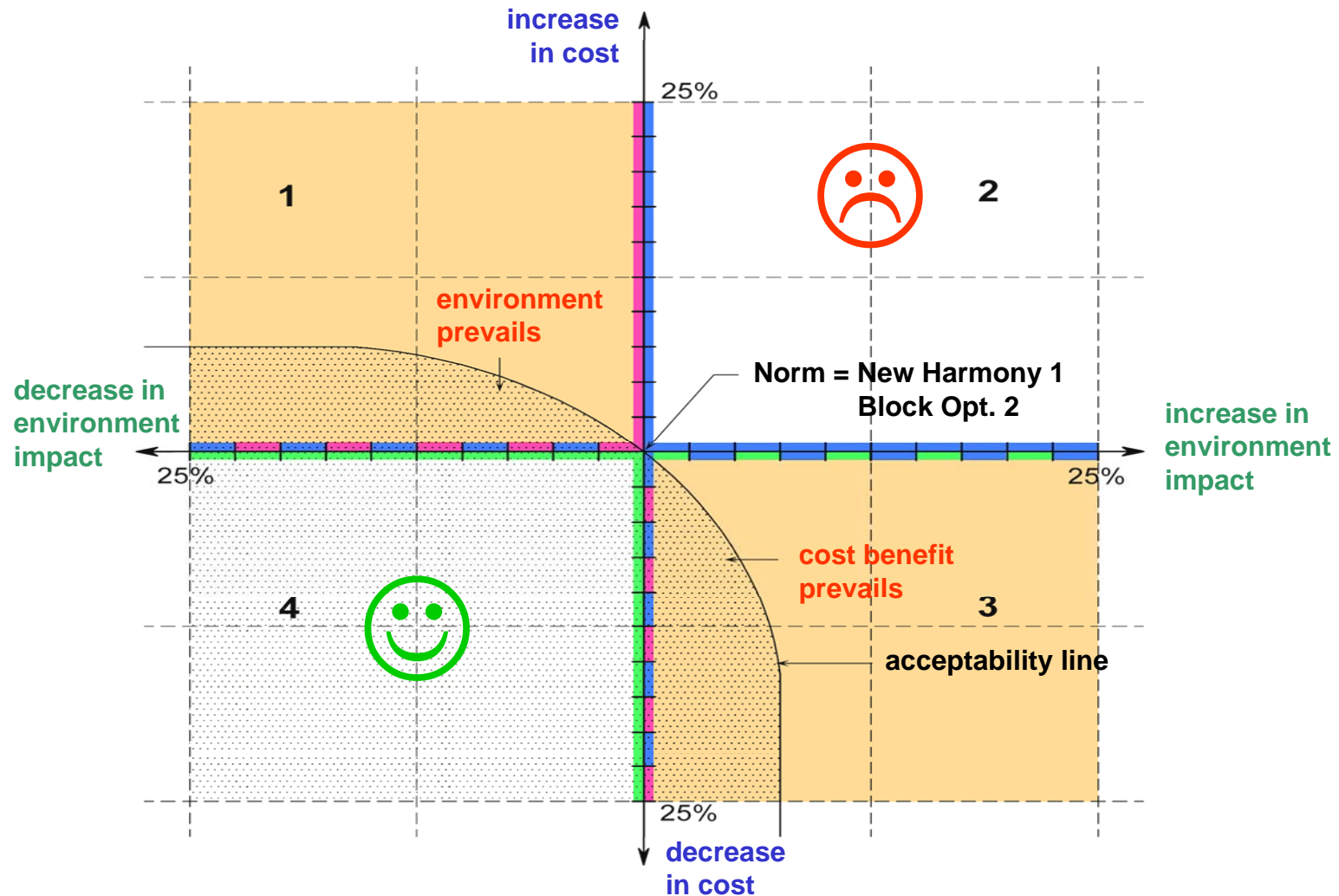
Decision Making



Computer Model (Cont'd)

- Decision Making Tool
 - Used for evaluating alternative proposals
 - Allows cost and environmental impacts to be compared
 - Compares proposed alternative against base building
 - Includes line of acceptability

Decision Making Tool





Detailed Methodology

3 Stage Life Cycle (Initial, Use and Maintenance and Disposal)

Approach :

1. Data Collection and Regionalisation
2. Consideration of Environmental Impacts
3. Characterization of Impacts
4. Normalization & Weighting
5. Operational Modelling, including repair and maintenance
6. End of life Modelling
7. Combining LCA/LCC as decision making tool



Environmental Impacts for Consideration in LCA Model

LAC model to measure outputs causing :

- **Climatic Changes** – Greenhouse gases tonnes of CO₂ eq
- **Acidification** – acid deposition landscapes causing damage to Ecosystem kg SO₂ eq
- **Ozone depletion** – damage to stratospheric ozone layer kg CFC 11 eq
- **Human toxicity (air and water)** – complex area kg of toxins eq. (assessment method by University of Leiden)
- **Ecotoxicity** – kg of toxins eq (assessment method as with human toxicity)
- **Photochemical Smog** – kg of ethane .eq
- **Resource Depletion** – non renewable mineral extraction tonnes of materials.
- **Waste** classified into hazardous waste, waste to landfill, recyclable and reusable waste, and waste to public filled areas eg. tonnes of materials/litres of waste oils
- **Water consumption** across the lifecycle (liters).

Regionalisation

- Collection of LCI data which match the production profiles of local materials as closely as possible
- Process analysis of local materials
- Transport:- detailed study
- Electricity mix:- Electricity Generation Regionalisation
- Energy Mix:- regionalisation of fuel mix
- Waste/Recycling and end of life modelling

Selection of Database(s)

- Large database to generate known outputs per production of each building material
- Database to have a suitable provenance with established / recognized methodology for data collection.
- Database rules need to be transparent on key issues :
 - location
 - feedstock energy
 - carbon cycle (timber)
 - primary and delivered energy, definitions + fuel
 - database needs to be 'regionalised'

REGIONALISATION

Process includes :

1. Collection of data from relevant local sources
2. Review of production processes for key materials (Data Gathering Workshops)
3. Energy mix e.g. – natural gas or coal
4. Review of production efficiency
5. Transport – up to factory gate
6. Clean Technology and Environmental regulations.

Formulation of SE ASIA / South China database of Construction Materials.

LCA Methodology: Inventory Analysis

LCA Data Sources

- Internationally recognised databases
 - Industry data: APME, IISI, Cement Manufacturers
 - ETH (Swiss Research Institutes)
 - IVAM (University of Amsterdam, Netherlands)
 - IDEMAT (TU Delft, Netherlands)
 - NREL (U.S. National Renewable Energy Laboratory)

- Cross checking data to ensure that data is accurate, complete, representative, repeatable and minimum variation (e.g. matching embodied energy data (MJ/kg) of building materials in local and overseas literatures).

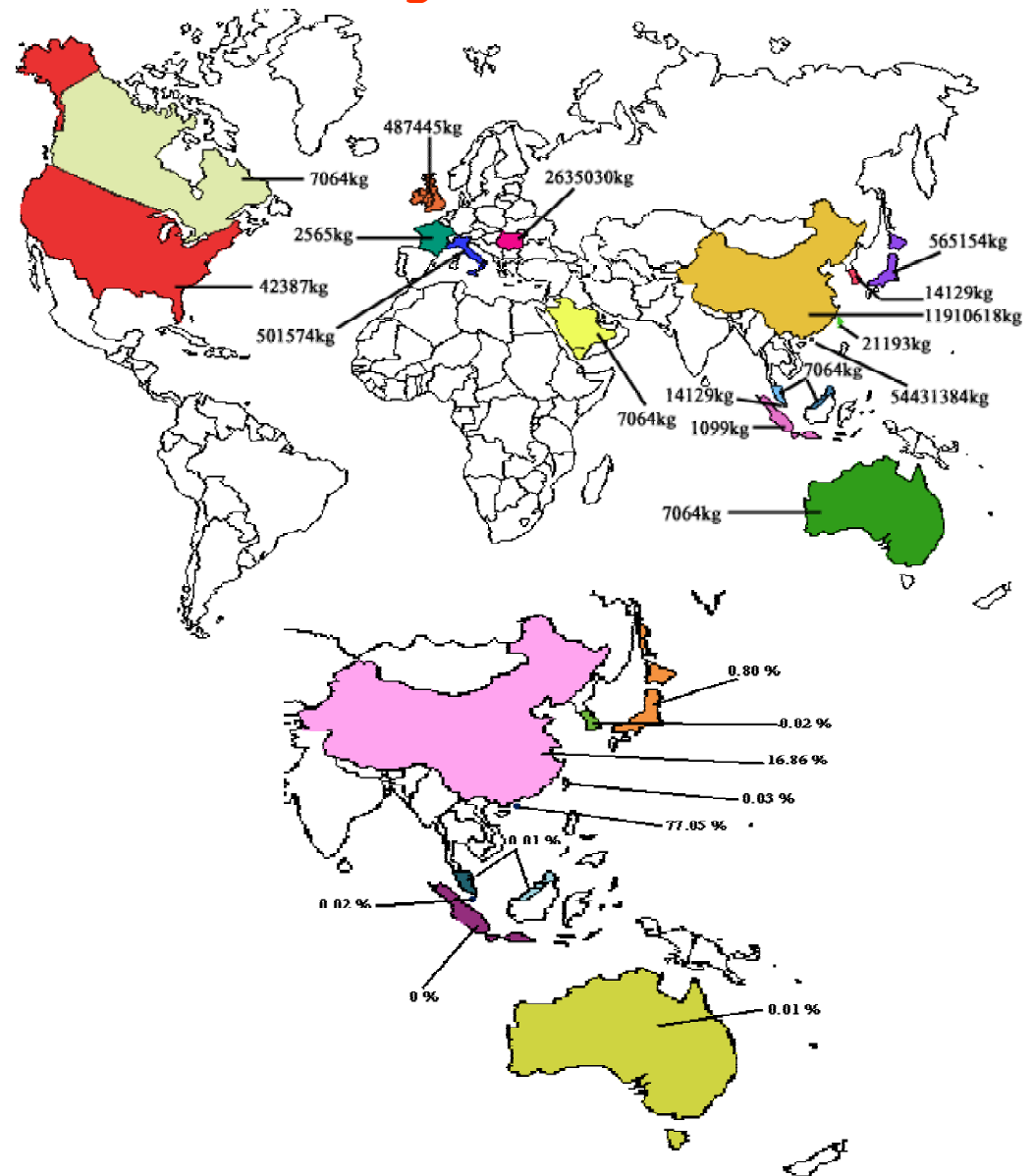
Database Evaluation

When evaluating LCI data the team used the following criteria:

1. Match of production process
2. Match of raw material inputs
3. Match of pre-manufactured material inputs
4. Match of proportion of each material
5. Match of by-products generated

Transportation Study

1. Identification of Key Building Materials
2. Find Source/Origin of Building Materials
3. Spilt into functional units
4. Identify Primary/dominant manufacturing source
5. Identify transportation mode
6. Calculate transport distance and associated environmental impacts





REGIONALIZATION

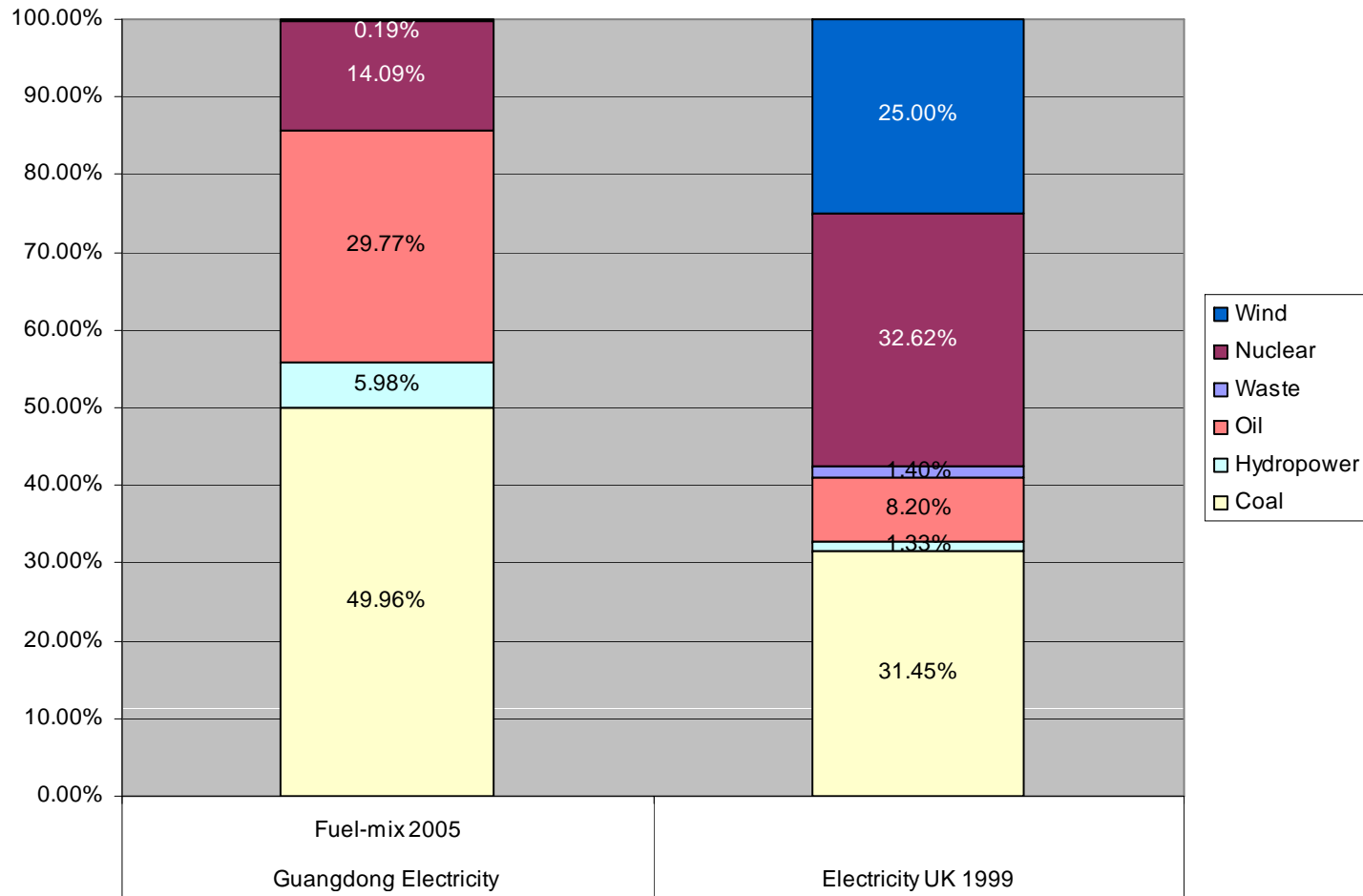
(factory gate to end of life)

Data are currently only until factory gate

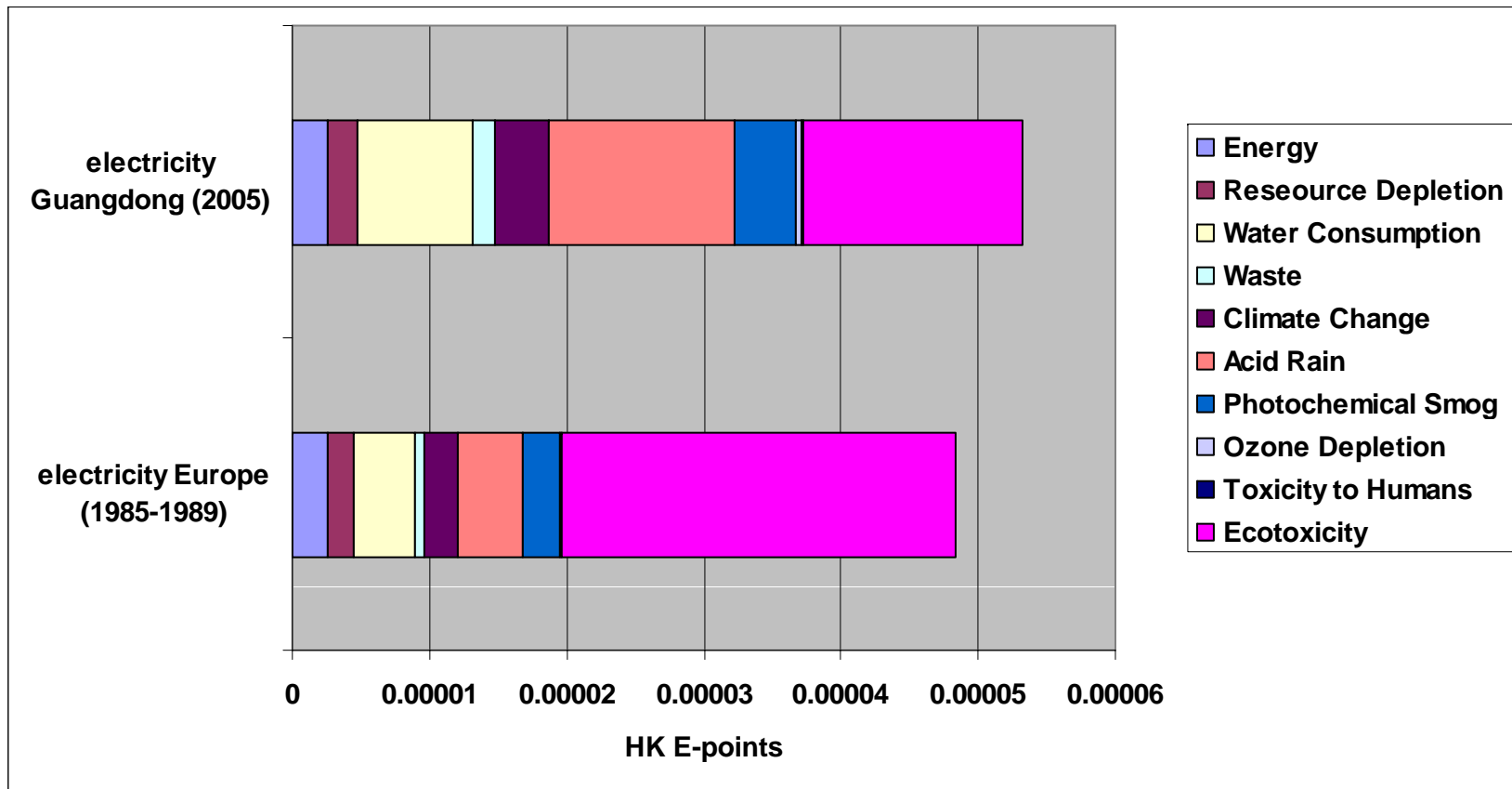
Post factory gate outputs for each material require assessment e.g.

1. Transport to site
2. Transport from site at end of life
3. Construction waste
4. Demolition waste at end of life
5. Recycling + Reuse
6. Hazardous waste, etc

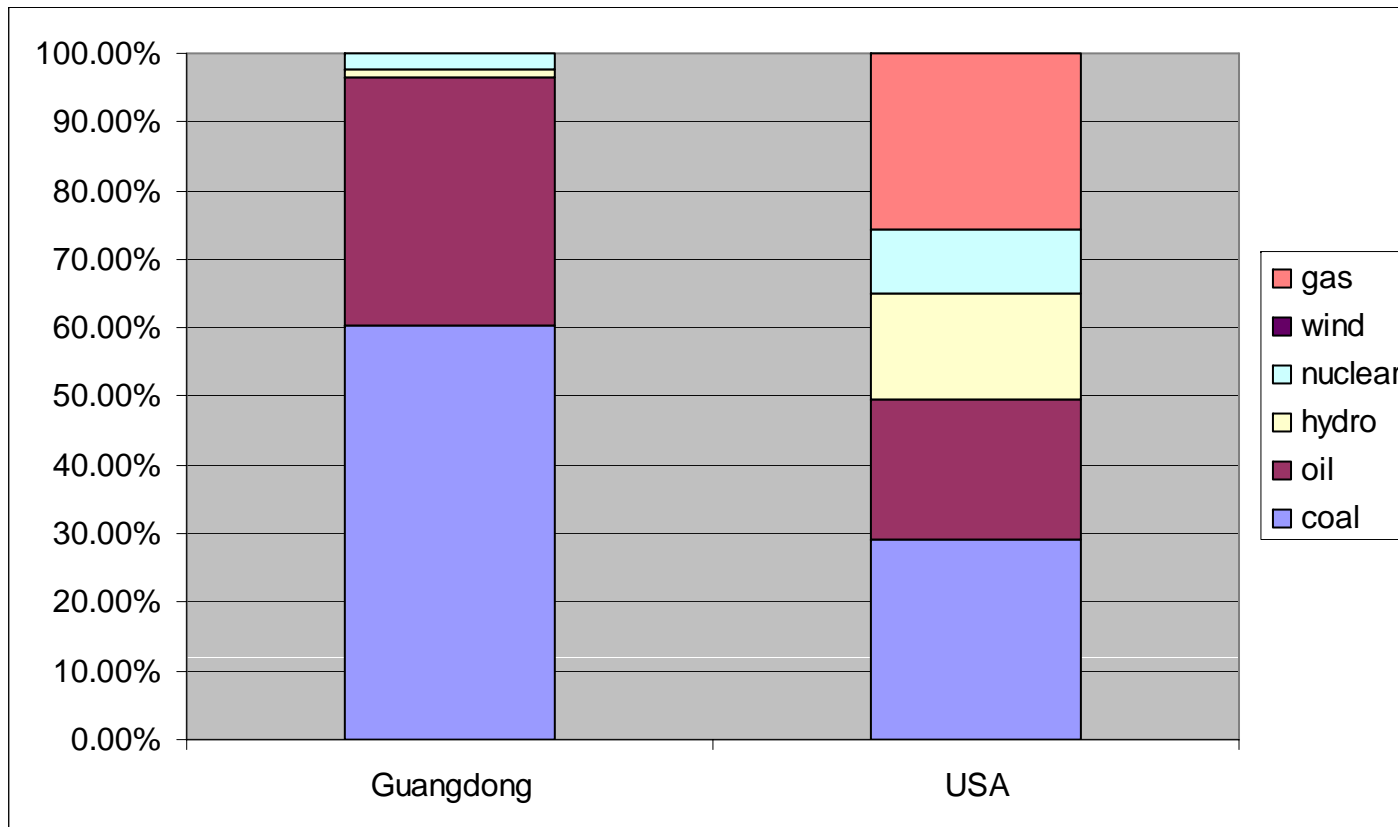
Electricity Fuel Mix



Regionalisation: Electricity Mix



Regionalisation: Energy Mix (incl. electricity)



LCA Data Retrieval – HKHA projects

Concrete grade 30	Aluminium – Extruded	Silicone Sealant	Glass - Toughened	Tiles - Clay Quarry
Concrete grade 35	Aluminium – Mill	Rubber	Glass - Georgian Wired	Tiles - Glazed Ceramic
Precast Concrete	Aluminium - Powder Coated	Neoprene Gaskets	Glass - Mirrored	Tiles - Glass Mosaic
Precast Concrete Paving	Aluminium – Anodised	Fibreglass	Paint - Wood Preservative	Tiles – Homogenous
Concrete Blocks - Solid	Copper Pipes	Mastic Asphalt	Paint - Aluminium	Tiles – Granite
Concrete Blocks - Hollow	Copper – Sheet	Asphalt	Paint - Zinc Chromate	Tiles – Rubber
Cementitious Waterproofing	Brass	Timber – Hardwood	Paint - Plastic Emulsion	Vitreous China
Steel - Reinforcement	Lead - Sheet	Timber - Teak	Paint - Acrylic	UPVC Pipes - Class D
Steel - Hot Rolled Sections	Mineral Wool	Timber - Plywood Luan	Paint - Synthetic	Plastic Pipes
Steel - Sheet	Extruded Polystyrene	Timber - Plywood Hardwood	Cement Based Waterproof Paint	PVC Conduits
Steel - Galvanised	Polystyrene	Timber - Marine Plywood	Paint - Bitumastic	UPVC Lining
Steel - Zinc Coated	Polysulphide Sealant	Glass - Clear Float	Paint - Cellulose Lacquer	UPVC Lining
Stainless Steel - Mill	PVC Mastic Sealant	Glass – Translucent	Paint - Epoxy	Gunmetal

LCA Data Retrieval – HKHA projects

Cast Iron – Piping	Cement Board	Copper – Cable	Paint - Prepolymer Sealer	PVC Coating - Cable
Ductile Iron – Pipes	Cement Sand Render	Glass – Frangible	Plastic – Sheet	Stainless Steel - Hairline
Stainless Steel - Piping	Cement Sand Screed	Glass - Georgian Wired Obsc	Plastic Door	Stainless Steel - Polished
Acrylic Sheet	Chromium Brass - Ironmongery	Glass Blocks	Plastic Laminate	Steel - Cable
Aluminium – Cast	Chromium Plated Brass	Paint - Alkali Resisting Primer	Plastic Pads	Timber - Formwork
Aluminium - Stove Enamel	Concrete - 20/20	Paint - Formwork	Plastic Sheet	Timber - Plywood MDF
Aluminium Mill Finish - Ribbed	Concrete - Spun	Paint - Moisture Sealer	Polycarbonate Sheet	Timber - Tackboard
Bitumen	Concrete Waterproof	Paint - Polyurethane Sealer	Polyethylene Foam	UPVC Pipes - Class E

LCA Data Retrieval – TKH new-material list

Floor Hardener	Tile - artificial marble (imported)	Wall paper - vinly and fabric	Barrisol translucent membrane	glass laminated low-e (entirely imported)
Adhesive for carpet	Tile - artificial marble (local)	Gypsum board	stone	glass laminated low-e (entirely local)
Carpet Nylon	Granite paving	Aluminium foil	skim coat plaster	glass tougened low-e (import + local processing)
Carpet Wool	Granite paving	concrete grade 15	paint - thermoplastic	glass tougened low-e (entirely imported)
Fireproofing paint (intumescent paint)	Limstone / Marble	concrete grade 20	cast zinc alloy	glass tougened low-e (entirely local)
lightweight screeds	Lightweight concrete	concrete grade 40	Die cast zinc	glass - laminated frosted (local)
Fabric -cotton	Fibre cement	concrete grade 50	cast iron	Gypsum plaster board (U.S.)
Fabric - Nylon	Floor sealer	concrete grade 60	GRG paint	rock wool
Fabric-polyester	Bronze	Glass - opaque laminated	glass - laminated (local)	fluorocarbon coating for external use
Tile - artificial granite (local)	Stainless steel - textured	Conglomerate stone	glass - laminated (import + local processing)	moisture resistant finish to ceiling board

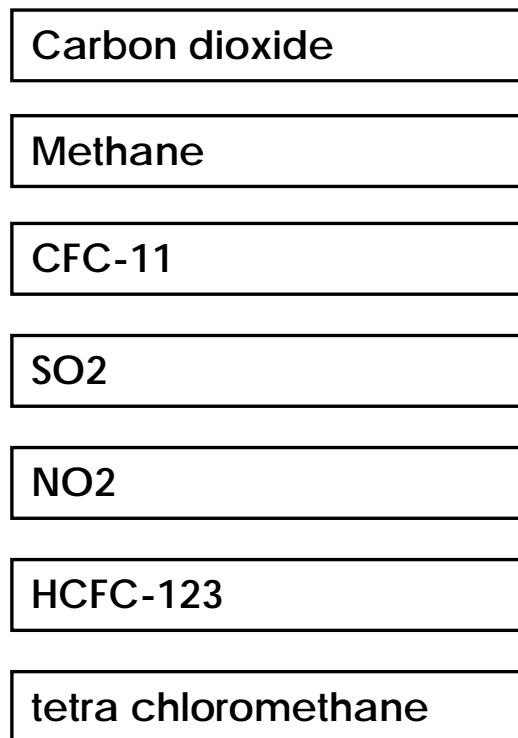
Life Cycle Inventory for a material

No	Substance	Compartiment	Unit	Steel ETH U Europe
1	Zr95 to water	Non mat.	mBq	13.1
2	Zr95 to air	Non mat.	nBq	169
3	Zr Air emissions	Air	æg	6.5
4	Zn65 to water	Non mat.	mBq	2.09
5	Zn65 to air	Non mat.	µBq	11.3
6	Zn (ind.) Solid waste	Soil	æg	49.9
7	Zn	Water	mg	14
8	Zn	Air	mg	18.3
9	zinc (in ore) Raw materials	Raw	æg	441
10	zeolite	Raw	æg	509
11	Y90 to water	Non mat.	µBq	3.71
12	xylene	Water	æg	264
13	xylene Other emissions	Air	mg	3.16
14	Xe 138 to air	Non mat.	mBq	784
15	Xe 137 to air	Non mat.	mBq	71.7
16	Xe 135m to air	Non mat.	Bq	2.89
17	Xe 135 to air	Non mat.	Bq	29.2
18	Xe 133m to air	Non mat.	mBq	86.2
19	Xe 133 to air	Non mat.	Bq	171
20	Xe 131m to air	Non mat.	mBq	58.3
21	wood (dry matter) ETH	Raw	g	5.2
22	wood	Raw	mg	333
23	water	Raw	kg	21.7
24	waste heat to water	Non mat.	kJ	87.2
25	waste heat to soil	Non mat.	kJ	16.3
26	waste heat to air	Non mat.	MJ	12
27	W Liquid waste	Water	æg	7.39
28	VOC as C	Water	æg	839
29	vinyl chloride	Water	nq	2.15

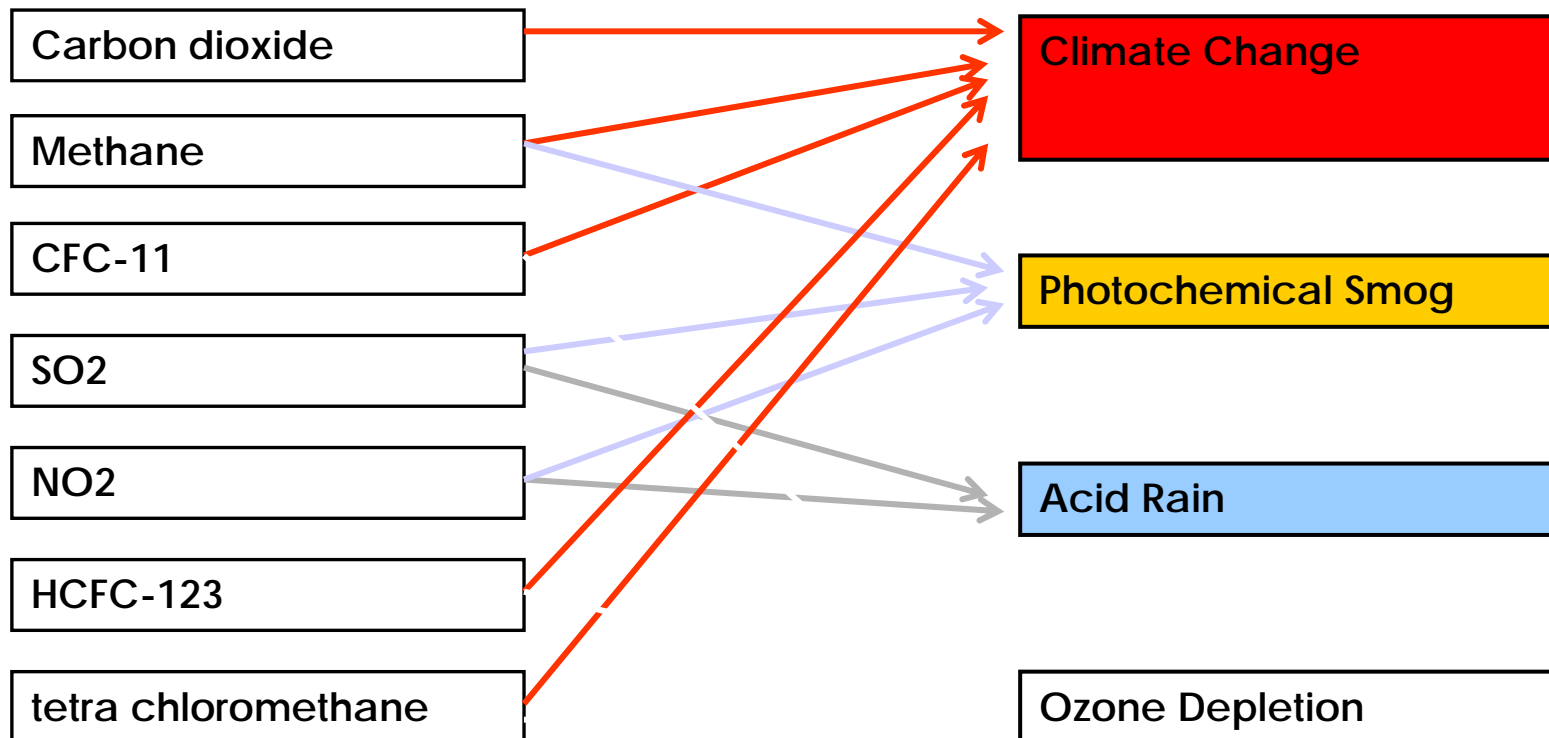
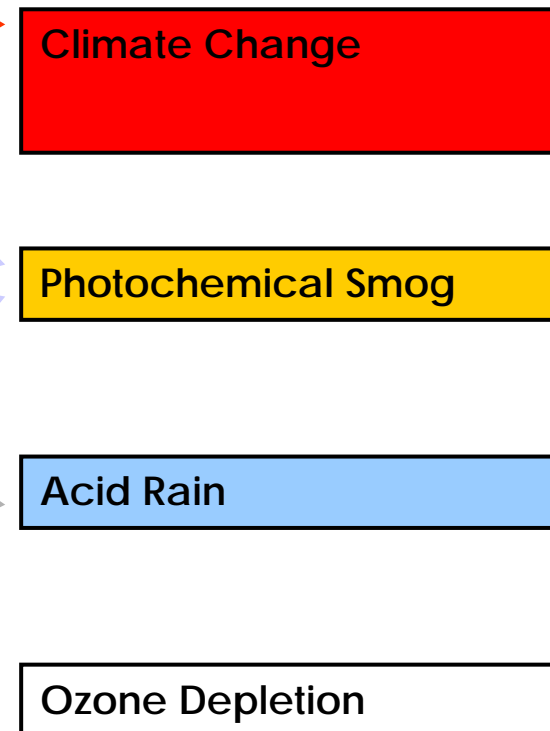
Life Cycle Impact Assessment - Classification

Assignment of the LCI results under different impact categories

Air Emission of LCI Data



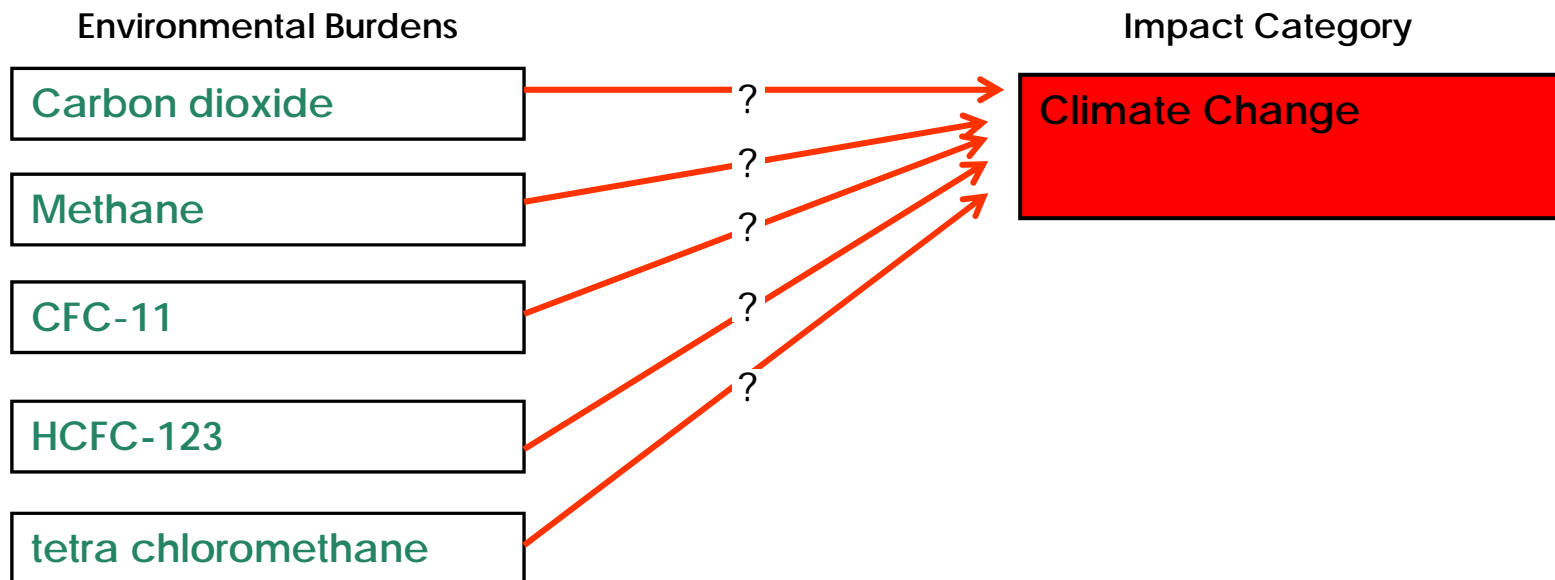
Impact Categories



After Classification - assignment of environmental burdens

We need to assign or quantify the contribution of an environmental burden (intervention) to the impact for each category of impact.

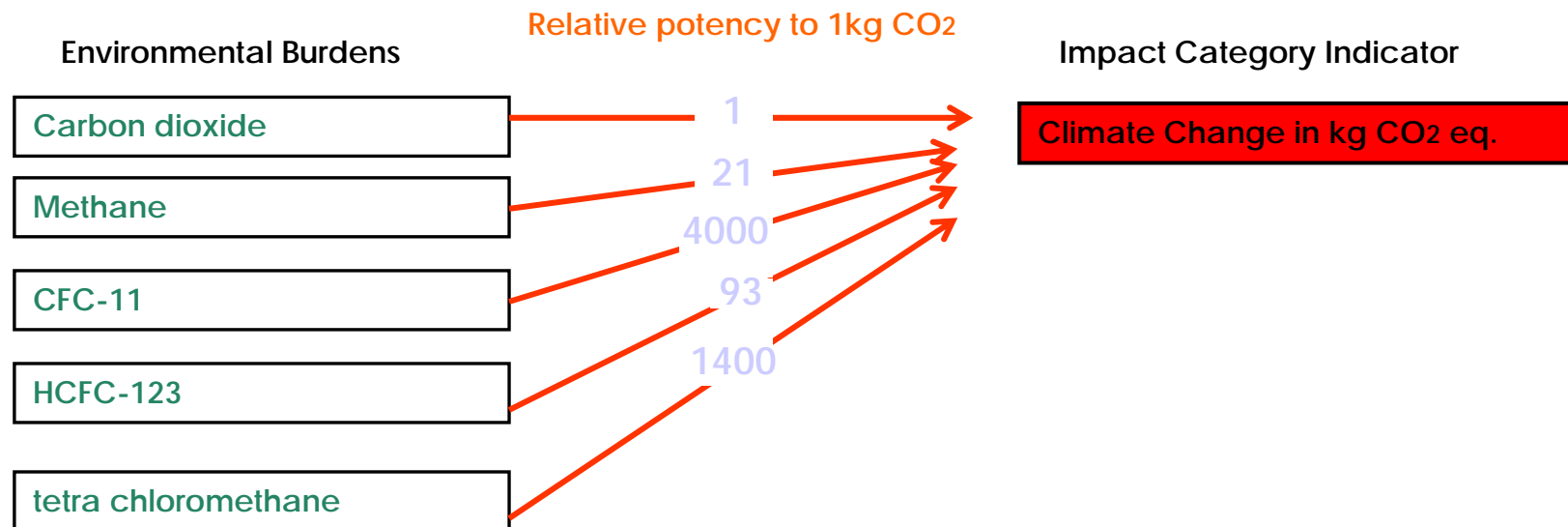
The process is called **Characterisation**.



Characterisation (cont'd)

"Characterisation provide an estimate of the relative climate-change between environmental burdens....."

"One burden which makes a contribution which is considered to have a contribution to carbon dioxide equivalent climate-change impact, or 'potency', of 1." ¹



¹Howard N., Edwards S. & Anderson J., 1999. BRE methodology for environmental profiles of construction materials, components and buildings. BRE, London, UK.

Collating Environmental Impacts

Outputs

CO₂
SO₂
NO_x
CO
VOC
N₂O
Mg
HCL
CR
Ag
Etc.

Characterized Impacts

Acid Rain	kg SO ₂ eq.
Climate Change	kg CO ₂ eq.
Energy	MJ
Resource Depletion	kg Sb eq.
Water Consumption	litres
Waste	kg
Photochemical Smog	kg ethane eq.
Ozone Depletion	kg CFC11 eq.
Toxicity to Humans	kg toxic eq.
Toxicity to Ecosystems	kg toxic eq.

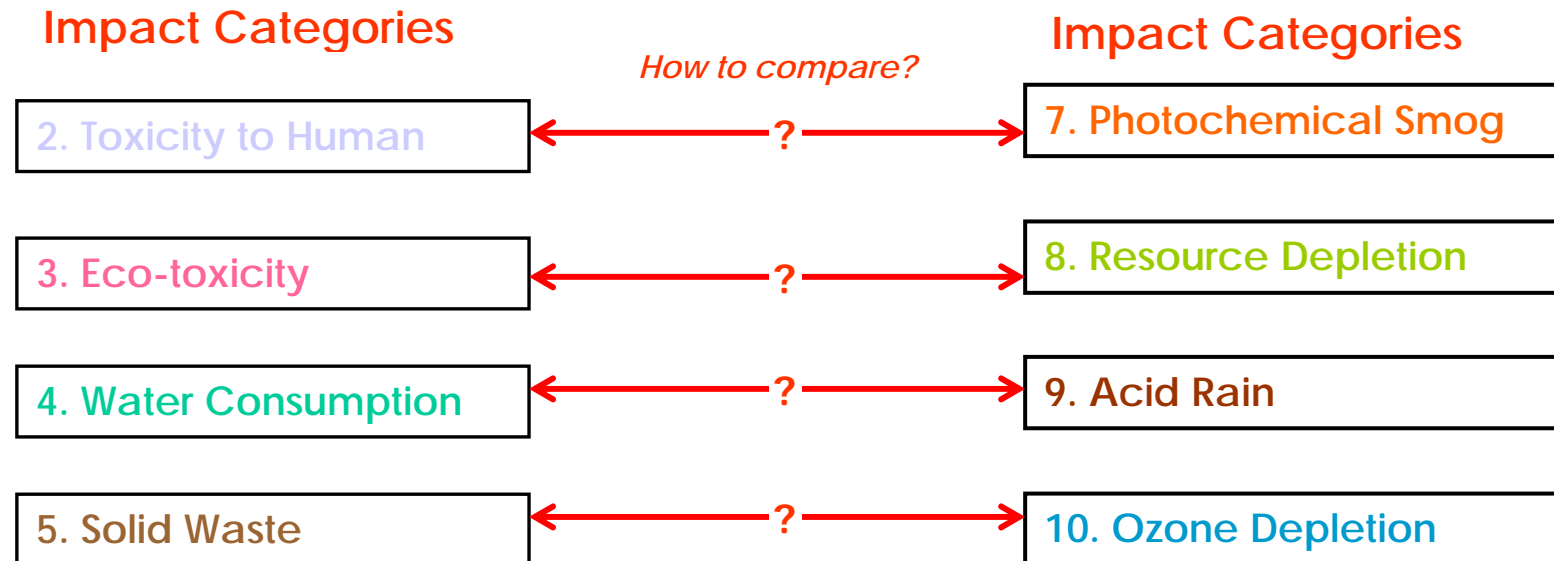
Characterisation Profile - 1kg Steel Rebar

Issues	Units	Characterised Data
Energy	MJ	17.1
Resource Depletion	Kg Sb eq.	0.000000289
Water Consumption	litre	16.1
Waste	kg	0.0878
Climate Change	kgCO ₂ eq.	1.8
Acid Rain	kgSO ₂ eq.	0.0102
Photochemical Smog	kg ethene eq.	0.00103
Ozone Depletion	kg CFC-11 eq.	0.000000176
Toxicity to Humans	kg Tox. eq.	1.1
Toxicity to Ecosystem	kg Tox. eq.	787.1775

After Characterisation

We need to express impact indicator data in a way that **can be compared among impact categories**.

The process is called Normalisation.





Normalisation

- Government, UN or World Bank sources where possible
- Common source where possible
- Common dateline where possible
- Appropriate population data used for data source

Normalisation (cont'd)

The **Norm (Local)** used for the **HKHA study** was the total annual emission or “resource use” of one HK citizen per annum

- *e.g. The Norm for climate-change is **the total annual CO2 equivalent emission of one HK citizen***

Normalisation (cont'd)

The normalisation procedures normalised the characterised results *by dividing by selected reference values (Norm)*.

- e.g.
- $$\text{Normalised (Local) Data (Climate Change)} = \frac{\text{Characterised Climate Change (in CO}_2\text{eq.)}}{\text{Total annual CO}_2\text{ emission of one HK citizen}}$$

(Data source: HK SAR EPD 2000)
- The Normalised (Local) Data For 1kg Steel – Rebar = Total sum of all normalised (Local) data of all the 10 environmental impacts

Normalised Profile for 1kg Steel Rebar

Issues	One HK Citizen	Normalised Data
Energy	115000 MJ/person/year	0.00015
Resource Depletion	52 kg/person/year	0.00000001
Water Consumption	13800 litre/person/year	0.00012
Waste	2.6 tonnes/person/year	0.000033
Climate Change	5900 kgCO ₂ eq./person/year	0.000304
Acid Rain	19 kgSO ₂ eq./person/year	0.00052
Photochemical Smog	2.4 kg ethene eq./person/year	0.00043
Ozone Depletion	0.02 kg CFC-11 eq./person/year	0.000009
Toxicity to Humans	45300 kg Tox./person/year	0.000024
Toxicity to Ecosystem	408000 kg Tox./person/year	0.00193
Normalised (Local) Data for 1kg of Steel Rebar Sum		0.0035



Weightings

- Global
- Regional
- Local

HK Weighting (Local)

HK weighting (local) determined from HKHA workshops in Dec 2002.

- Academics, government departments and professional institutions
- Building services installation contractors
- Housing department internal staff
- Leading construction contractors
- Major material suppliers
- Estate managers, tenant representatives and non government organisation

Issues	HK Weighting (Local) (%)
Acid rain	7.23
Climate change	8.02
Energy	10.57
Ozone depletion	6.95
Photochemical smog	13.68
Resource depletion	8.34
Toxicity to ecosystem	9.11
Toxicity to humans	10.80
Waste	14.91
Water consumption	10.39

Weighting (Cont'd)

Three classifications of weighting (Local, Regional and Global Levels) determined from workshop

Weighted (Local) Data for Climate Change =
Normalised (Local) data x
by relative local weighting for climate change (8.02%)

Weighting Environmental Impacts for 1kg Steel Rebar

Issues	HK Weighting (Local) (%)	HK E-points
Acid rain	7.23	0.0038
Climate change	8.02	0.00244
Energy	10.57	0.00157
Ozone depletion	6.95	0.00006
Photochemical smog	13.68	0.00585
Resource depletion	8.34	0.00000005
Toxicity to ecosystem	9.11	0.0175701
Toxicity to humans	10.80	0.000262
Waste	14.91	0.000498
Water consumption	10.39	0.00121
Total HK E-points of 1 kg Steel Rebar SUM		0.03324

HKHA LCA Result

- **HK E-Points** are the unit of measurement for all environmental impacts
- **1 HK E-Point = Impacts of 1 HK Citizen / year**



Operational Model

for HKHA Study and Swire Taikoo Hui LCA/LCC Projects

Operational Energy Modelling using *Visual DOE 3.1*

- A detailed building energy simulation programme that models:
 - **building's climate**
 - **construction**
 - **occupancy scheduling**
 - **heating, cooling, water heating and other equipments**
- A full-hourly building energy simulation programme that calculates energy use on an hourly basis

Energy simulations

The operational energy model in Visual DOE simulates how much **electricity** is consumed in **tenant and landlord areas** on:

- Space cooling (electricity)
- Space lighting (electricity)
- Small power loads (electricity)
- Fan operation (electricity)
- Transport energy e.g. lifts modelled by spreadsheet with pattern supplied by Swire

Occupancy patterns

The **operational energy model** simulates electricity consumption according to occupancy patterns of modelled **tenant and landlord areas**:

- People Occupancy Pattern (Weekday, Sat, Sun, Holiday)
- Lighting, Equipment Operation Pattern (Weekday, Sat, Sun, Holiday)
- Cooling Temp. & Fan Operation Pattern (Weekday, Sat, Sun, Holiday)
- Lift and or Escalator Operation Pattern (Weekday, Sat, Sun, Holiday)

Building Construction Details

Building construction details was referred to:

- **DLS validated construction details** for various building elements, e.g. roof, wall, partition constructions, glazing, spandrel, suspended ceiling and raised floor arrangements

Lighting and Equipment load calculations

Equipment and lighting power load for office tenant and landlord areas are derived from:

- **24-hour lighting and equipment operation pattern** referred to three Swire Premises and validation case (weekday, Sat, Sun, Holiday)
- **Design Lighting and Equipment Power Density** from project engineer and real LPD and EPD of operating premises for validation with bill

Daylighting simulations

Simulation of indoor daylight illuminance in accordance with:

- **Window size, window arrangement and shading arrangements,**
- **Type of glazing,**
- **Typical metrological year (TMY) daylight illuminance levels**

Heat-flow simulations

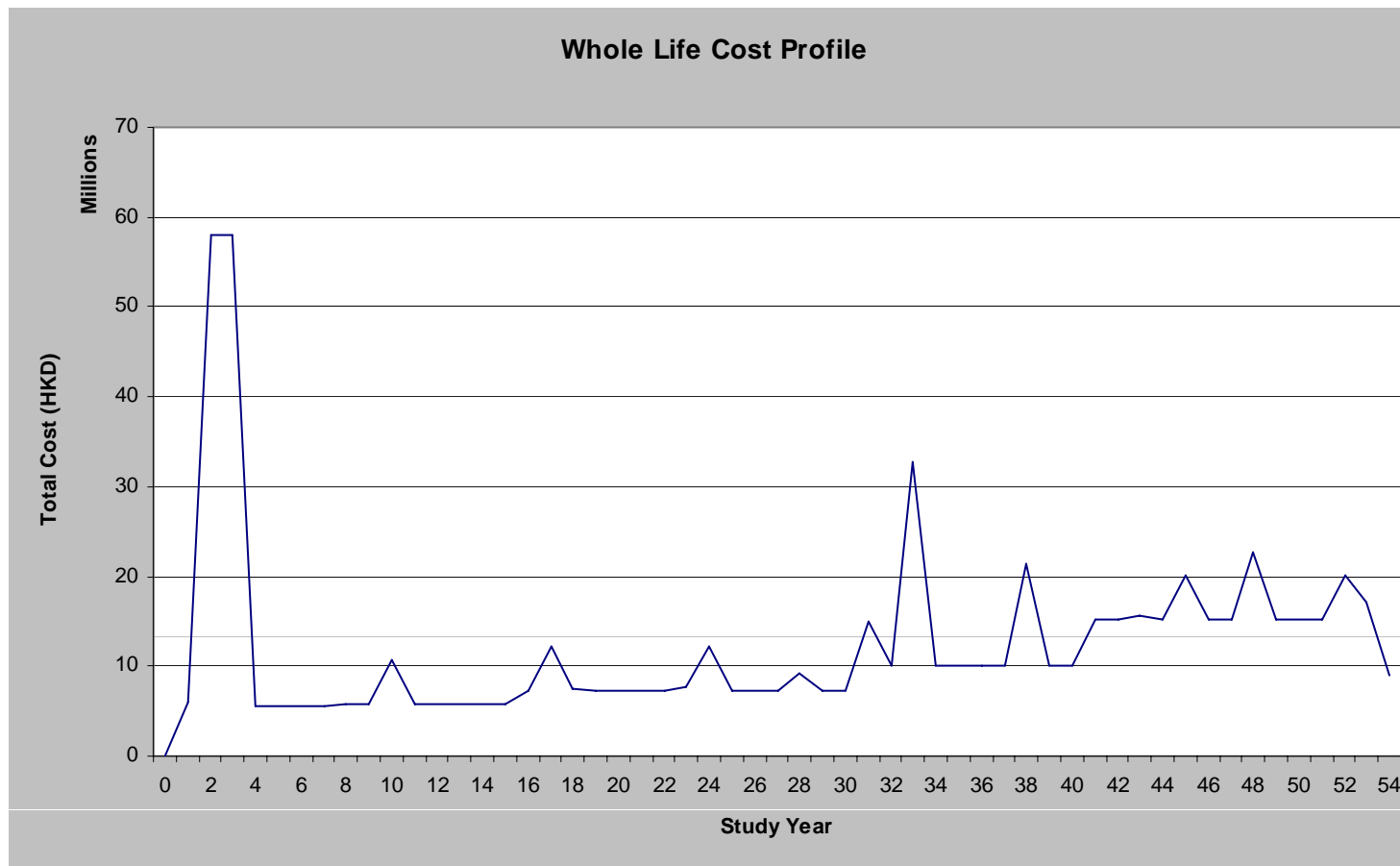
Simulation of external heat, solar heat and internal heat gain according to:

- **Thermal conductivity of building materials**
- **Shading coefficient, light transmission, U-factor of glazing,**
- **Internal heat gain from lighting, cooking, equipment, occupants**

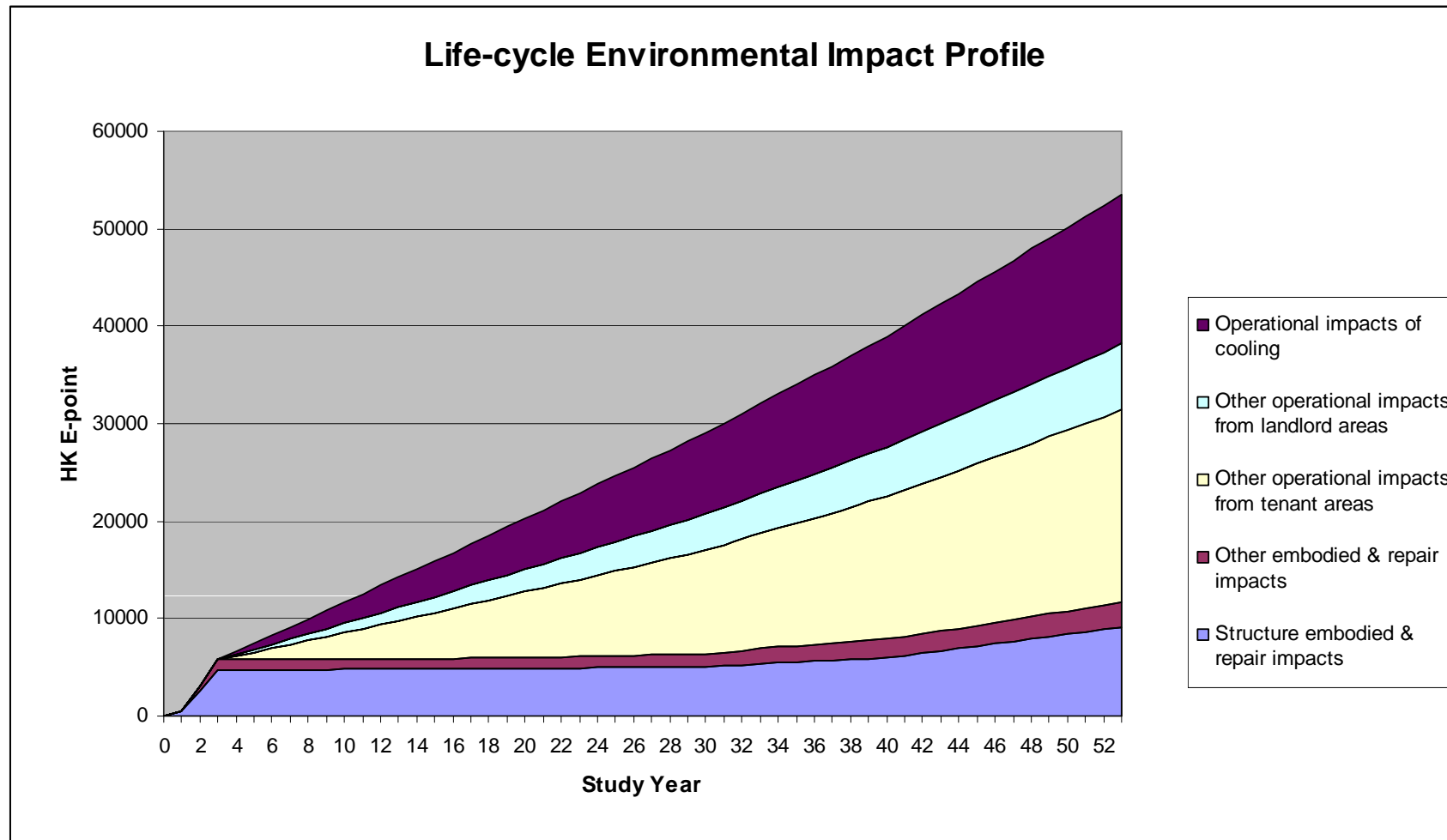


Results - Economic

Life Cycle Profile of Costs



Detailed Analysis of HKHA Block



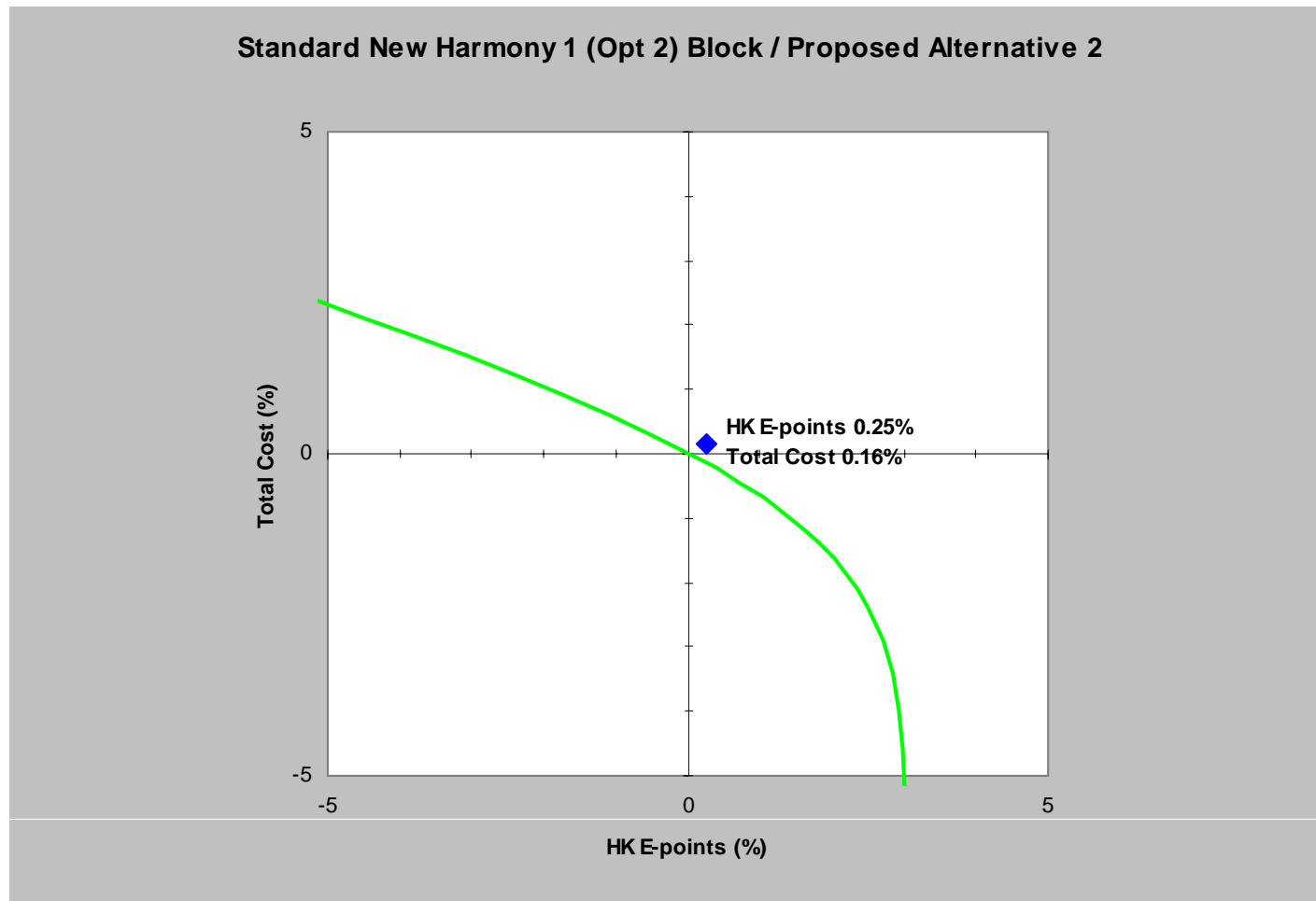


Alternative Designs / Materials



Non-viable Alternatives Studied

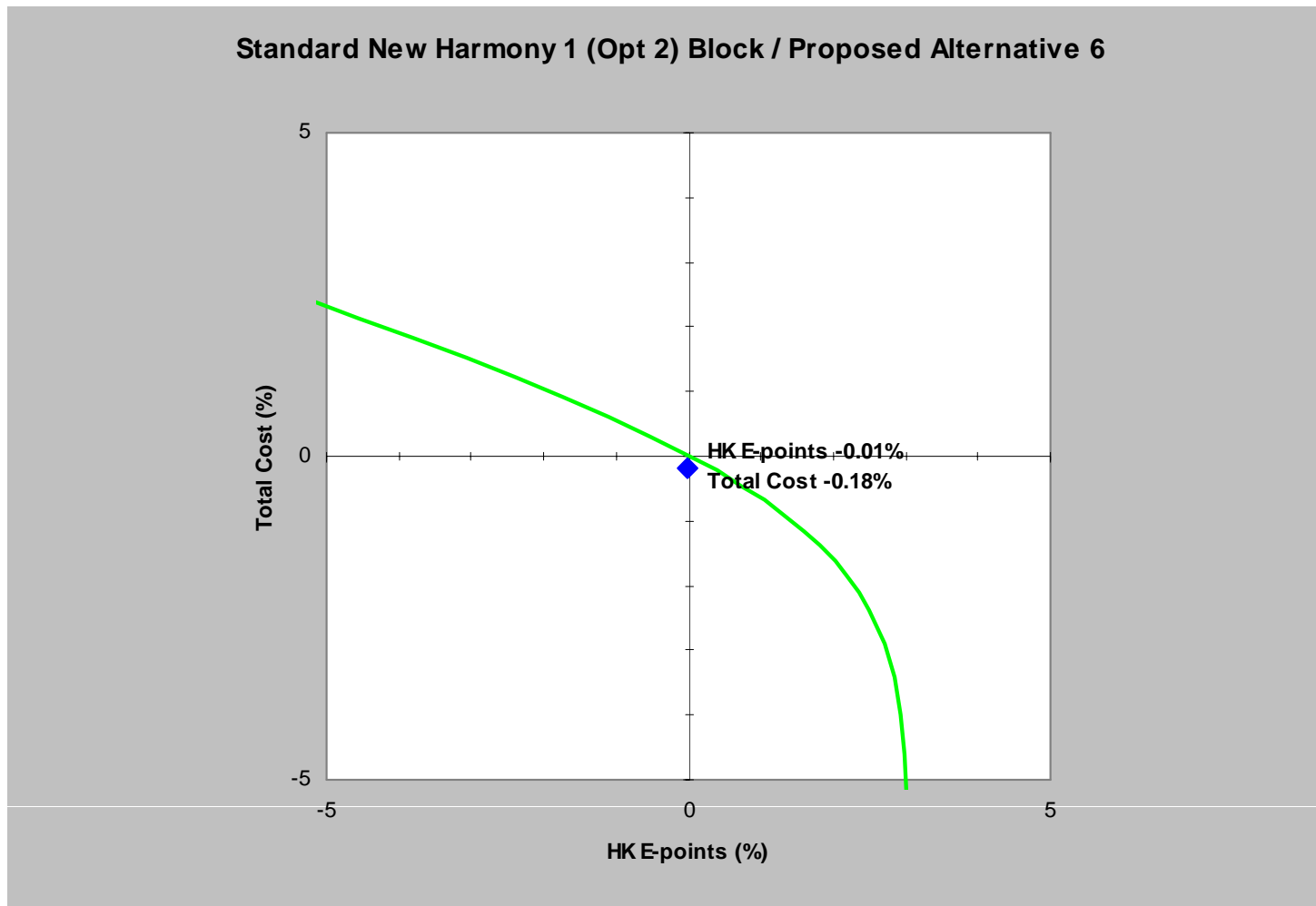
Ordinary Poland Cement Panel Wall to gypsum stud wall





Viab**le** Alternatives

Softwood Entrance Doors (& Kitchen Door)



Validation

- Peer Review

- LCA Methodology - Reviewed by DHV and BRE
- LCA Data Treatment - Reviewed by BRE
- LCC Methodology - Reviewed by BRE
- Weighting Methodology - Reviewed by DHV and HKU Psychology Consultant
- Operational Modeling - Reviewed by WSP

Outcomes

- A design tool to aid decision making has been demonstrated and validated
- Allows construction alternatives to be explored and tested quickly at all stages of the design and construction process
- Can be expanded to address HKHA's complete building stock and indeed all HK buildings
- Could help examine and test the sustainability of alternative, strategic planning policies can be combined with transport models and other consumption and waste models