13th ACCARNSI National Early Career Research Forum and Workshop
University of New South Wales – Manly Vale, 20-22 February, 2017

UNSW AUSTRALIA

Infrastructure Adaptability and Sustainability

Never Stand Still | Faculty of Engineering | School of Civil and Environmental Engineering

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Outline

- **Research Significance**
- **Research aim/approach**
- **Research method**
- **Case example**
- **Concluding remarks**

Research significance

Climate change → Infrastructure obsolescence → Adaptation

Warragamba dam

Collaroy beach protection

- enormous costs
- resource consumption/ waste production
- disruption to services

Look-ahead approach

Uncertainty → Design for Adaptability

Designed-in adaptation

Fortuitous adaptation

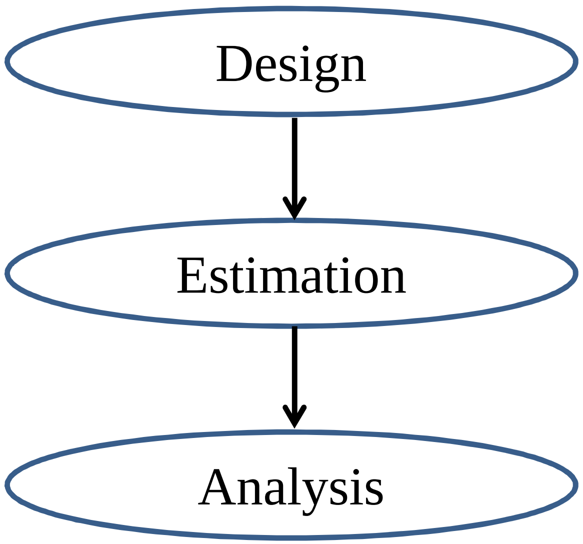
Extra upfront cost/effort !

adaptable infrastructure value – sustainability viewpoint

Research aim/approach

Establish viability of adaptable infrastructure

Comparative study – two forms of adaptation: A and NA



- Designed-in adaptability features
- Possible future adaptation

Costs, social and environmental issues

<u>Financial</u>: Real options analysis (ROA)
<u>Social/Environmental</u>: Life cycle assessment (LCA), Social/Environmental costing (SEC)

Research method

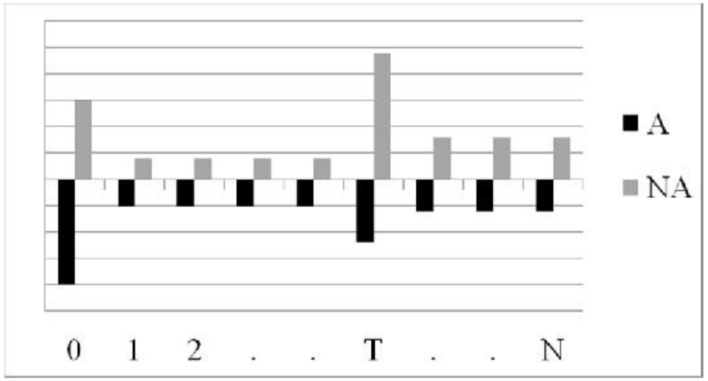
Financial analysis – ROA

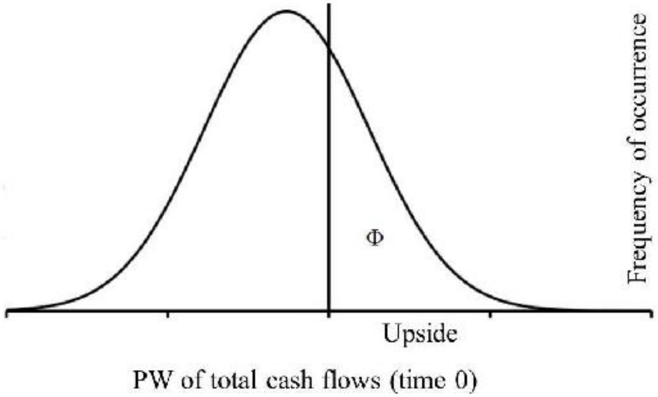
- Use of second order moment approach in DCF analysis

$$E[] = (O + 4M + P)/6$$
$$Var[] = (c - a/6)^2$$

$$E[X_t] = \sum_{k=1}^{m} E[Y_{tk}]$$
$$Var[X_t] = \sum_{k=1}^{m} Var[Y_{tk}] + 2\sum_{k=1}^{m-1} \sum_{l=k+1}^{m} Cov[Y_{tk}, Y_{tl}]$$

$$E[PW] = \sum_{i=0}^{n} \frac{E[X_i]}{(1+r)^i}$$
$$Var[PW] = \sum_{i=0}^{n} \frac{Var[X_i]}{(1+r)^{2i}} + 2\sum_{i=0}^{n-1} \sum_{j=i+1}^{n} \frac{Cov[X_i, X_j]}{(1+r)^{i+j}}$$





- Carmichael Equation: OV=Φ×UV

- Sensitivity analysis – discount rate (r) and adaptation time (T)

Carmichael and Balatbat (2010); Carmichael (2014)

Research method

Financial analysis – ROA

Options analysis – only looks at differences at time T

$$X_T = NA_T - A_T$$

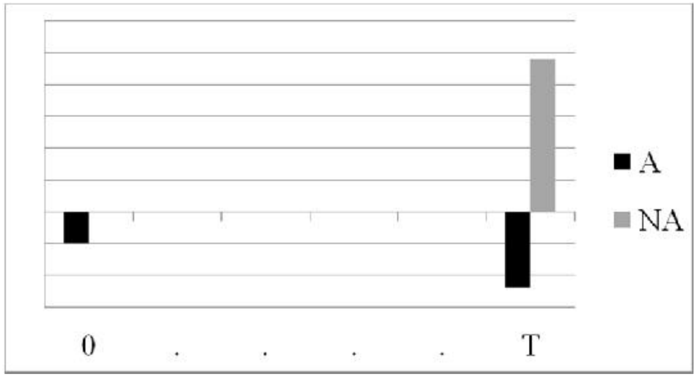
$$E[X_T] = E[NA_T] - E[A_T]$$

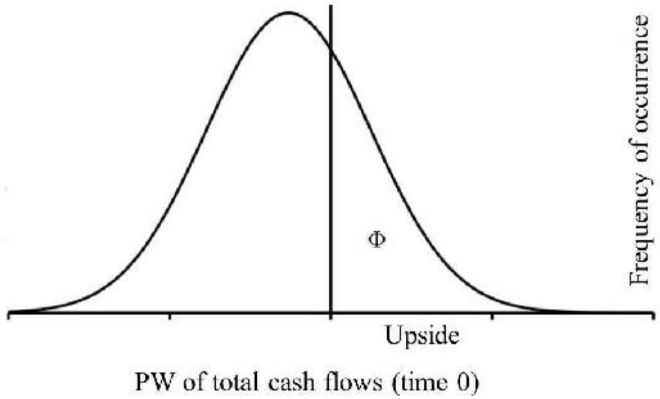
$$Var[X_T] = \left(\sqrt{Var[NA_T]} - \sqrt{Var[A_T]}\right)^2$$

$$E[PW] = \frac{E[X_T]}{(1+r)^T}$$

$$Var[PW] = \frac{Var[X_T]}{(1+r)^{2T}}$$

Adaptability value = $\Phi \times UV$

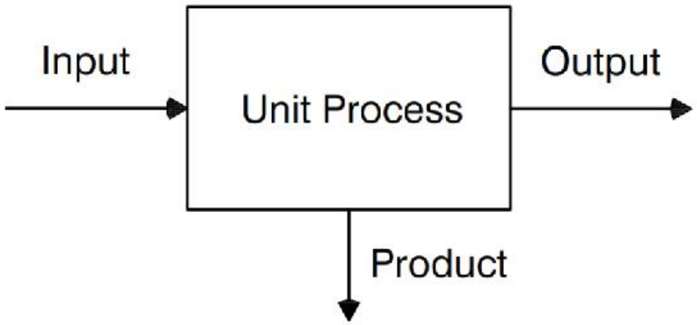




Research method

Social/Environmental analysis – LCA

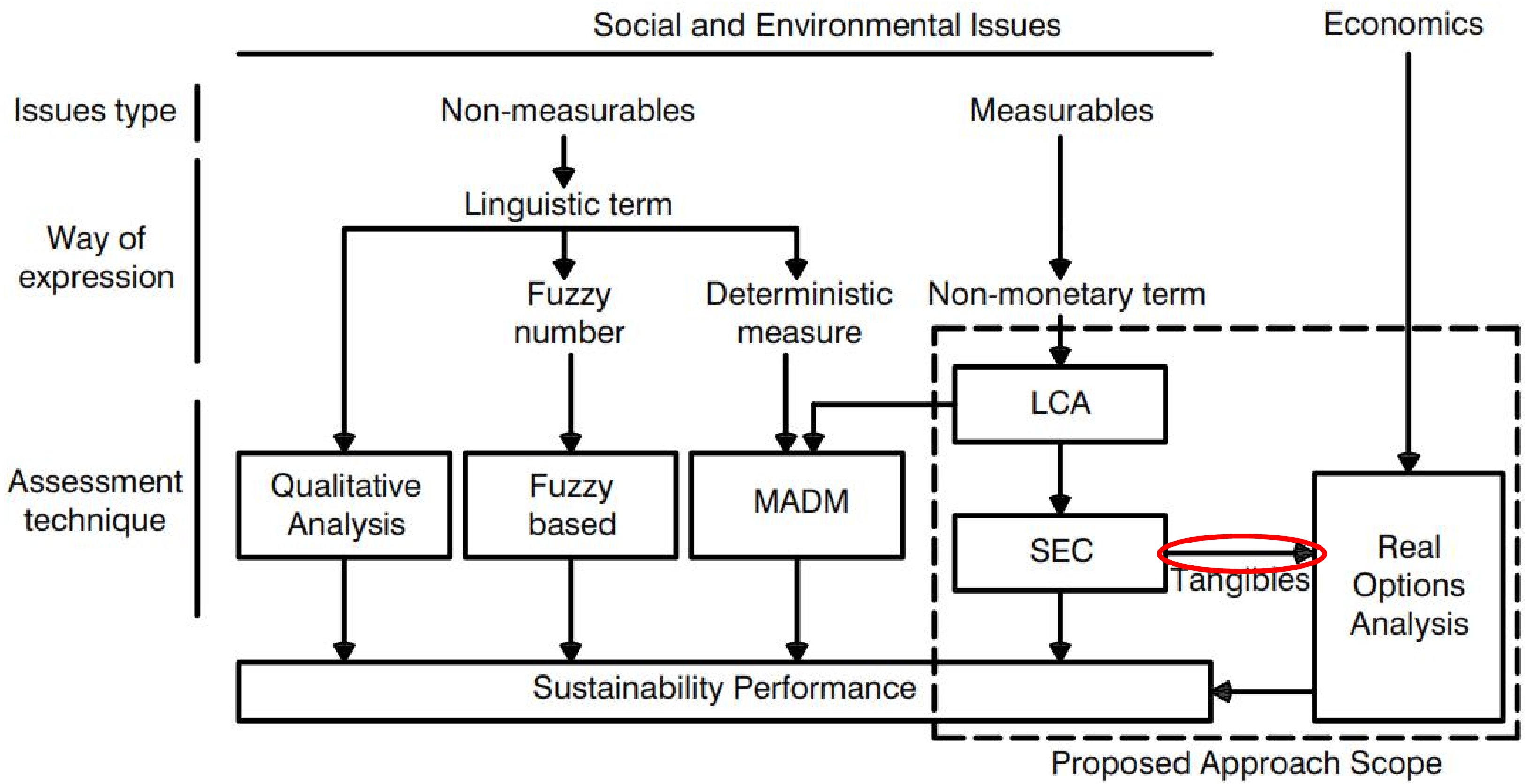
- Identify relevant social/environmental issues
- Quantify the issues (inventory flows)
- Compare NA and A (times 0, T)



ISO (2006); UNEP/SETAC (2009)

Research method

Sustainability analysis – ROA-SEC



Research method

Sustainability analysis – ROA-SEC

SEC techniques – shadow price estimation methods

- Policy tools (taxes, fines), Insurance cost, Pollution control cost, …
- Health/safety cost, Loss of productivity , Delay cost, …
- Replacement cost, Remediation cost, Waste treatment costs, …

$$X_T = (NA_{T,F} - A_{T,F}) + \sum_i (NA_{T,SE_i} - A_{T,SE_i})$$

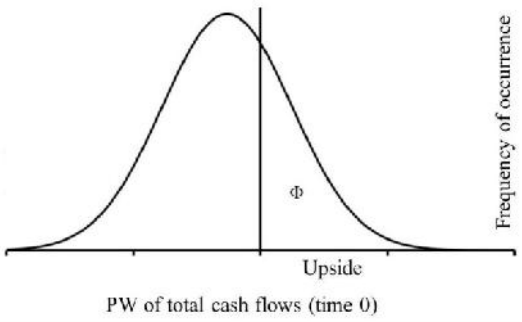
$$E[X_T] = E[NA_{T,F}] - E[A_{T,F}] + \sum_i E[NA_{T,SE_i}] - E[A_{T,SE_i}]$$

$$Var[X_T] = \left(\sqrt{Var[NA_{T,F}]} - \sqrt{Var[A_{T,F}]} + \sum_i \sqrt{Var[NA_{T,SE_i}]} - \sqrt{Var[A_{T,SE_i}]} \right)^2$$

$$E[PW] = \frac{E[X_T]}{(1+r)^T}$$

$$Var[PW] = \frac{Var[X_T]}{(1+r)^{2T}}$$

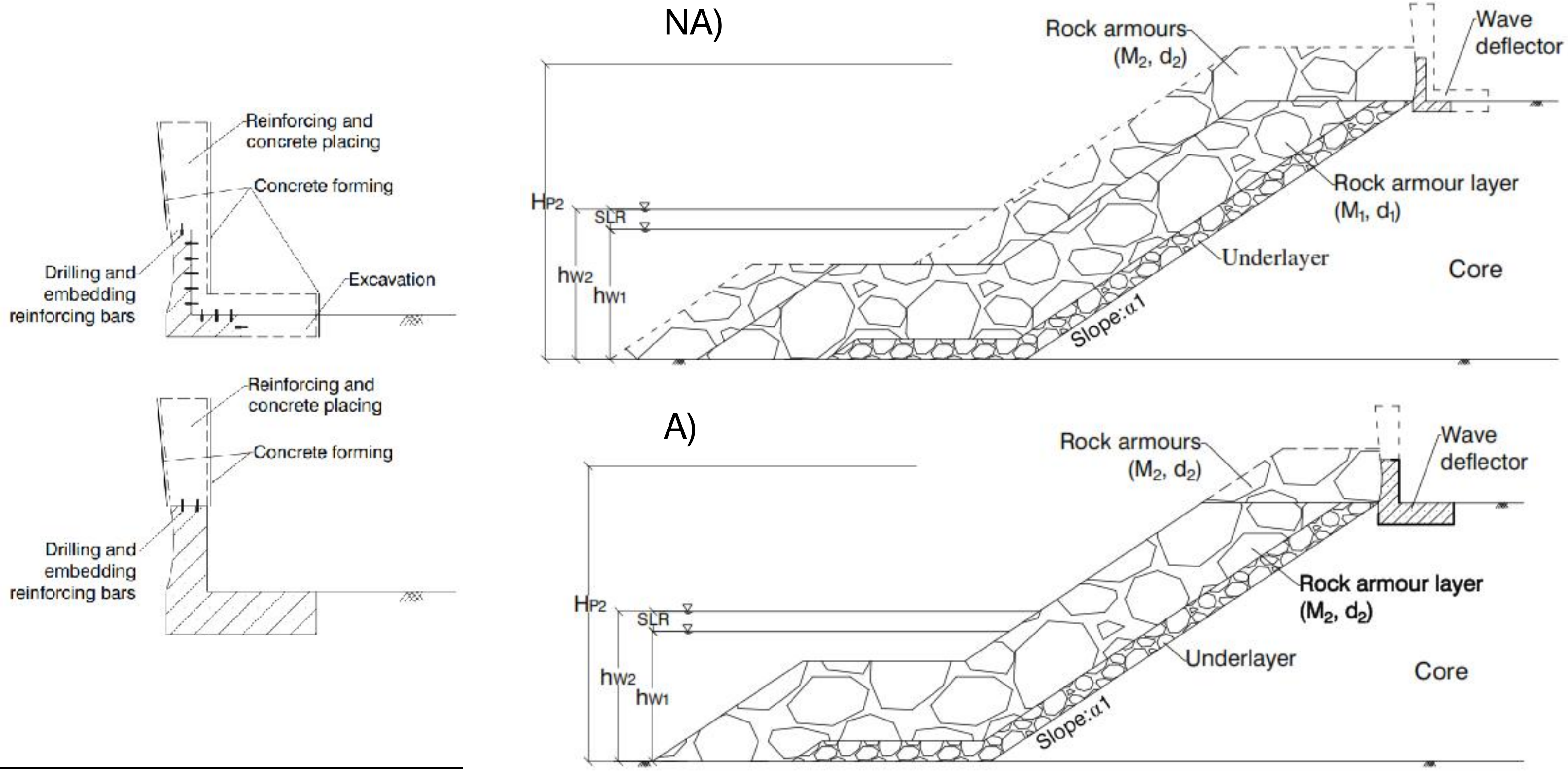
Adaptability value = ΦM



Case example – rock seawalls

Design

Designed-in adaptability features in A form	Future adaptation in NA form
• Build primary layer of larger armour units • Build parapet wall of stronger foundation	• Add bigger armour units on seawall face • Strengthen parapet wall foundation



NCCOE (2012a); Burcharth (2014)

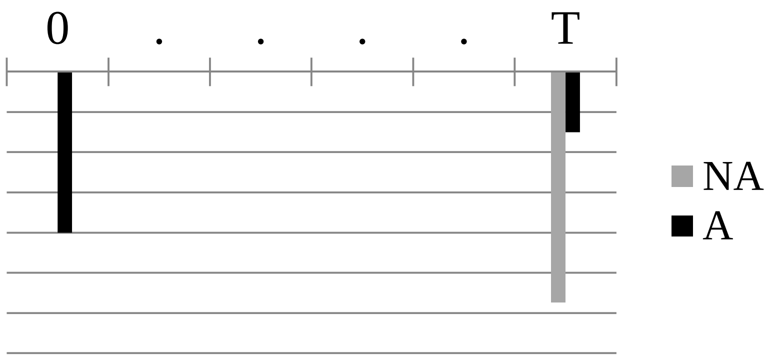
Case example – rock seawalls

Estimation – differences between A and NA forms

Construction activities considered

Time	A - Designed in form	NA - Non-designed in form
t = 0	Build armour layer of bigger rocks	
	Construct parapet wall foundation of bigger size	
t = T	Add rocks – on the crest	Add bigger rocks – on the crest and slope; in front of the toe
	Enlarge parapet wall – drilled anchors for wall; reinforced concrete	Enlarge parapet wall – drilled anchors for wall and foundation; reinforced concrete
		Pavement – remove and rebuild

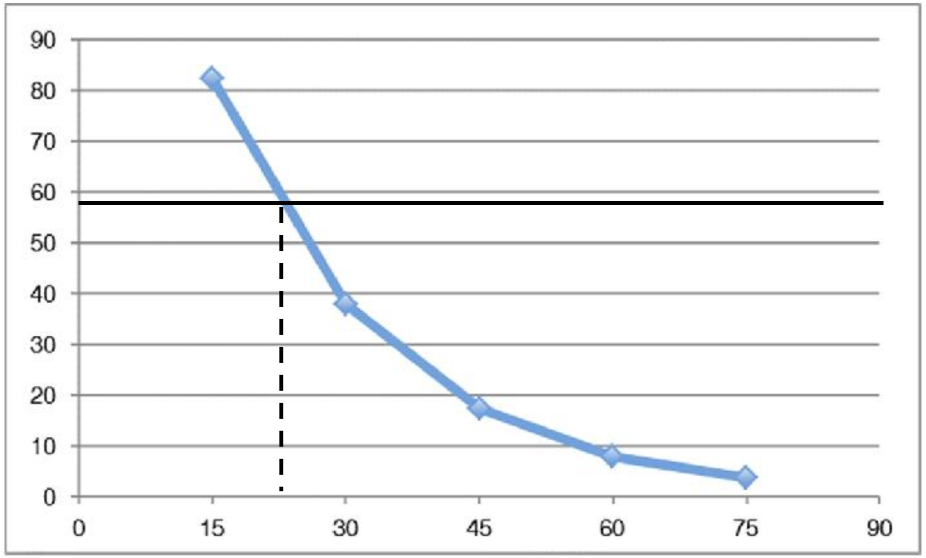
Schematic cash flow diagram



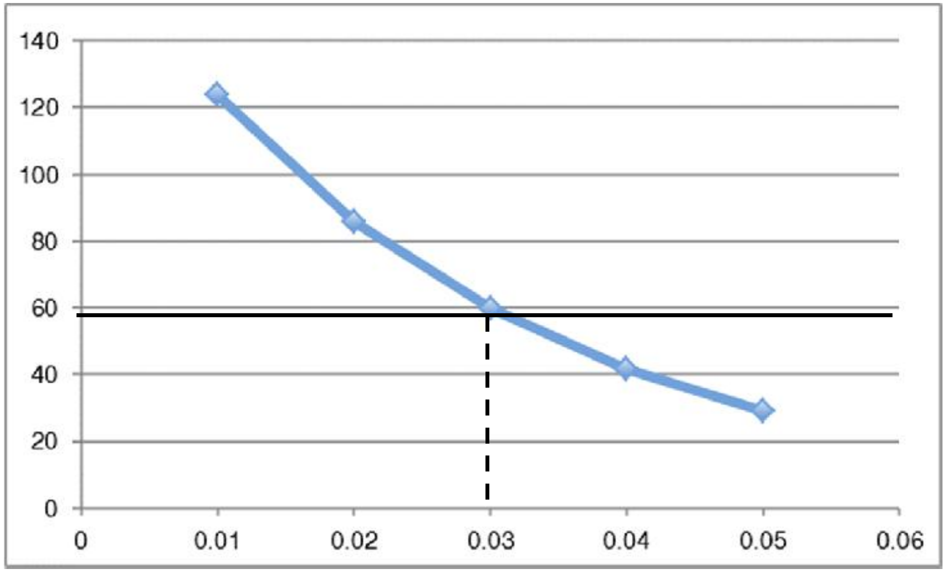
Case example – rock seawalls

Financial analysis – results

(A) extra upfront cost ≈ $60k



Change in adaptability value with T. r = 5% p.a.

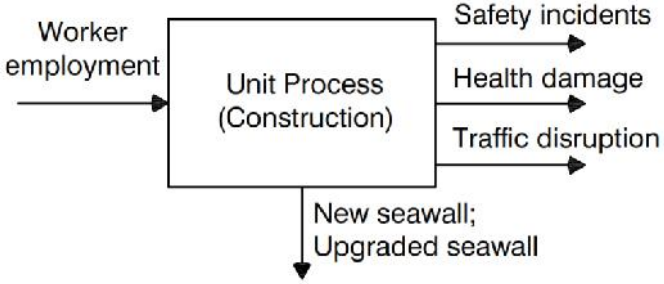


Change in adaptability value with r (p.a.). T = 35 yrs.

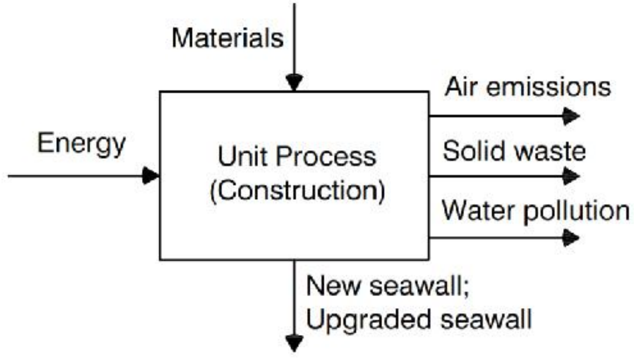
Case example – rock seawalls

Social/Environmental analysis – LCA results

SLCA



LCA



Sustainability issue		At t = 0	At t = T	Combined t = 0 and T (A-NA)
Environ.	Materials consumption (t)	664	-2,536	-1,872
	Energy use (GJ)	185.1	-447.4	-262.3
	Emissions (tonne CO2-e)	20.2	-32.1	-11.9
	Solid wastes (t)	29.3	-122.9	-93.6
	Water pollution (kg)	35	-160	-125
Social	Worker employment (h)	213	-855	-475
	Safety incidents (injuries no.)	0.0070	-0.0282	-0.0212
	Health damage (dBh)	4,933	-35,605	-30,672
	Traffic disruption (veh.h)	155	-686	-531

Case example – rock seawalls

Social/Environmental analysis – ROA-SEC

Sustainability issue	Adopted SEC methods
Materials consumption	-
Energy use	-
Emissions	Abatement cost (carbon tax), Damage cost
Solid waste production*	Waste treatment cost
Water pollution	Remediation cost
Worker employment	Contribution to society, Comfort value
Safety incidents	Insurance value, Loss of contribution
Health (noise pollution)	Loss of productivity
Traffic disruption	Replacement cost, Delay cost

Treatment of intangibles uncertainty

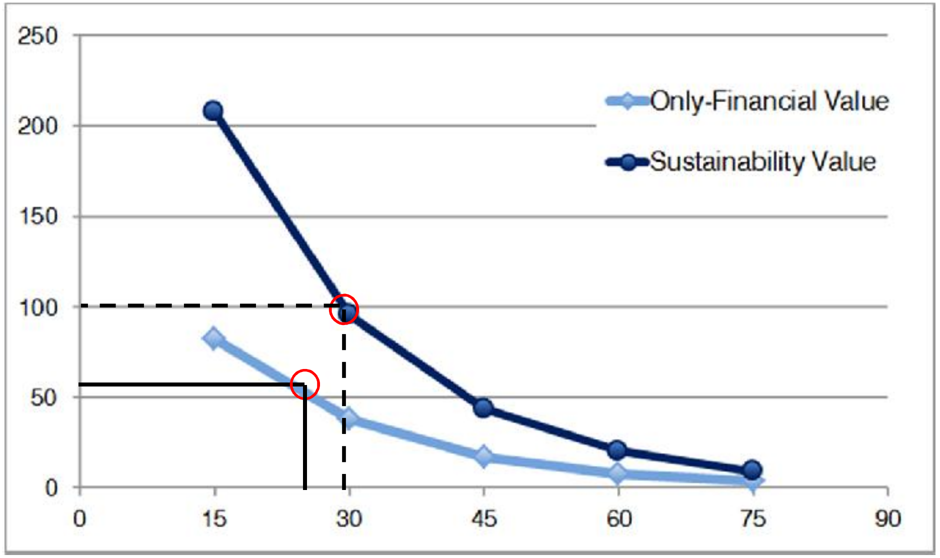
$$E[X] = \sum_{i=1}^{n} w_i \times E[x_i]$$

$$Var[X] = \sum_{i=1}^{n} w_i^2 \times Var[x_i]$$

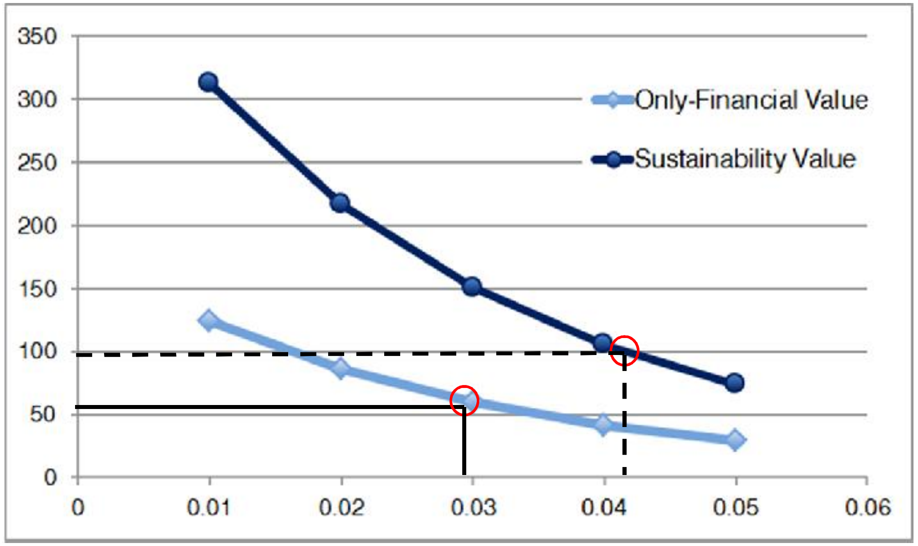
Case example – rock seawalls

Social/Environmental analysis – ROA-SEC results

(A) extra upfront cost
Only-Financial – $60k
Sustainability – $100k



Change in adaptability value with T. r = 5% p.a.



Change in adaptability value with r (p.a.). T = 35 yrs.

Potential for further encouraging investment in adaptability

Concluding remarks

- An **easy-to-use method** for financial valuation of investment in adaptable infrastructure presented.
- LCA could indicate **whether** infrastructure adaptability is sustainable… and whether inclusion of environmental/social criteria enhances viability.
- Sustainability incorporated in options analysis – ROA-SEC captures intangibles uncertainty and indicates **to what extent** environmental/social criteria enhance viability… potential for further encouraging investment.
- Methods **application demonstrated** … no general conclusions on the viability – need for individual analysis.

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Thank you for your attention