Part 2: Developing and assessing solutions using Multiple Criteria Decision Analysis (MCDA)

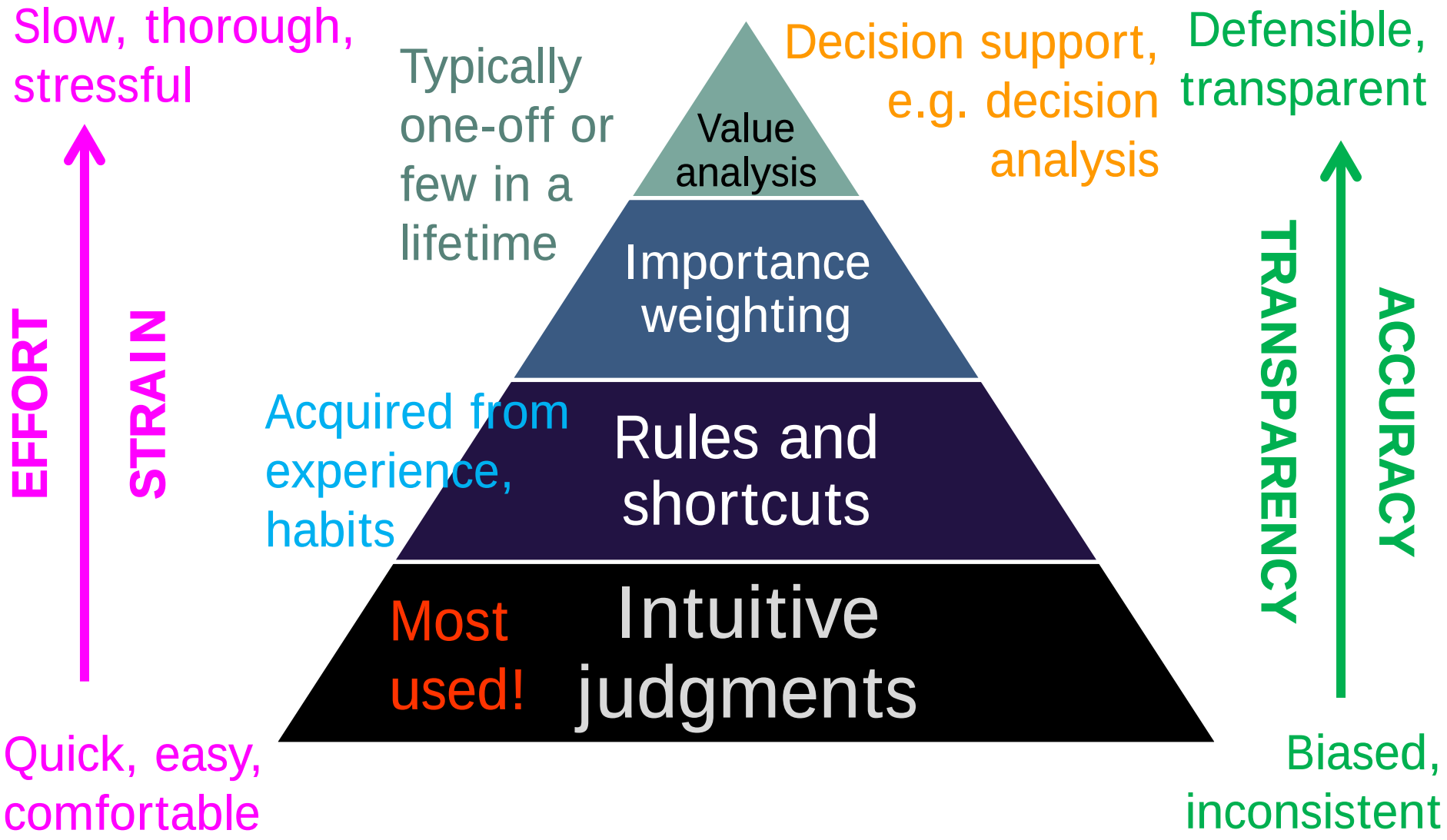
Dr. Lisa Scholten (TU Delft, NL)

IWA WWRR22 conference, 10 April 2022

TU Delft Delft University of Technology

The workshop organizers have received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 821051 and co-funded by Department of Biotechnology (DBT), Government of India under the umbrella of the Pavitra Ganga prokect www.pavitra-ganga.eu

Decision making approaches

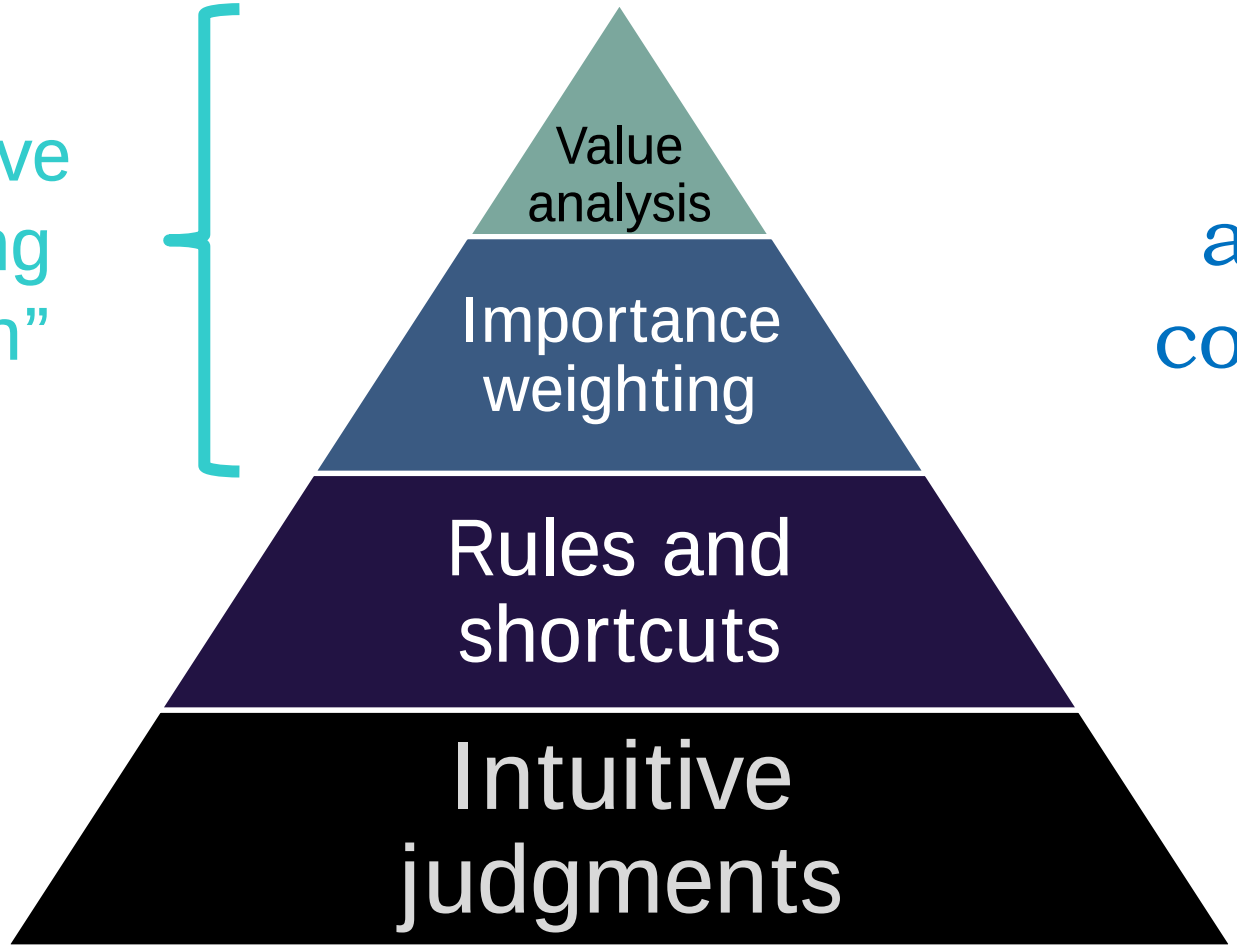


PAVITRA GANGA

Schoemaker, J.H. and Russo, E. 1993. *A pyramid of decision approaches.* California Management Review 36(1) 9-31.

Deliberative processing "intention"

Automatic processing "intuition"



Deliberative, structured ('rational') approach for consequential decisions

PAVITRA GANGA

Schoemaker, J.H. and Russo, E. 1993. *A pyramid of decision approaches.* California Management Review 36(1) 9-31.

Decision quality

2b. Relevant and reliable information

What is known or believed

2c. Clear values and trade-offs

What is wanted or hoped to achieve

How much one is willing to give up on one value to achieve another

2a. Creative alternatives

Possible actions / what can be done

1. Appropriate frame

Problem or opportunity to be tackled?

3. Sound reasoning

Guides to best action given the values and information at hand

4. Commitment to action

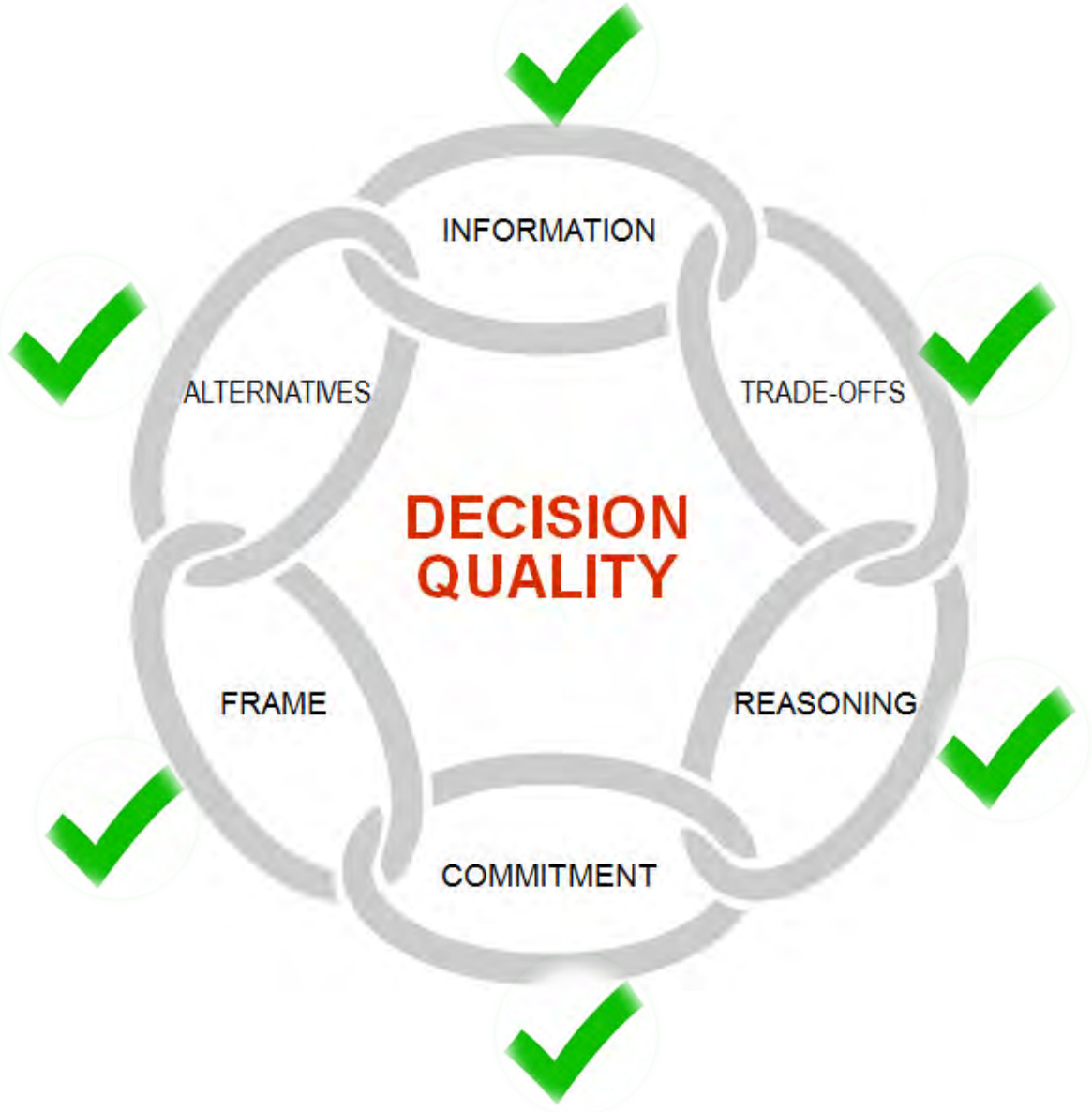
Intentions do not suffice, action is what makes change

PAVITRA GANGA

Spetzler, C., Winter, H., Meyer, J. 2016. *Decision Quality: Value Creation From Better Business Decisions.* Springer

Conditions for decision quality

A good decision requires quality in each of these

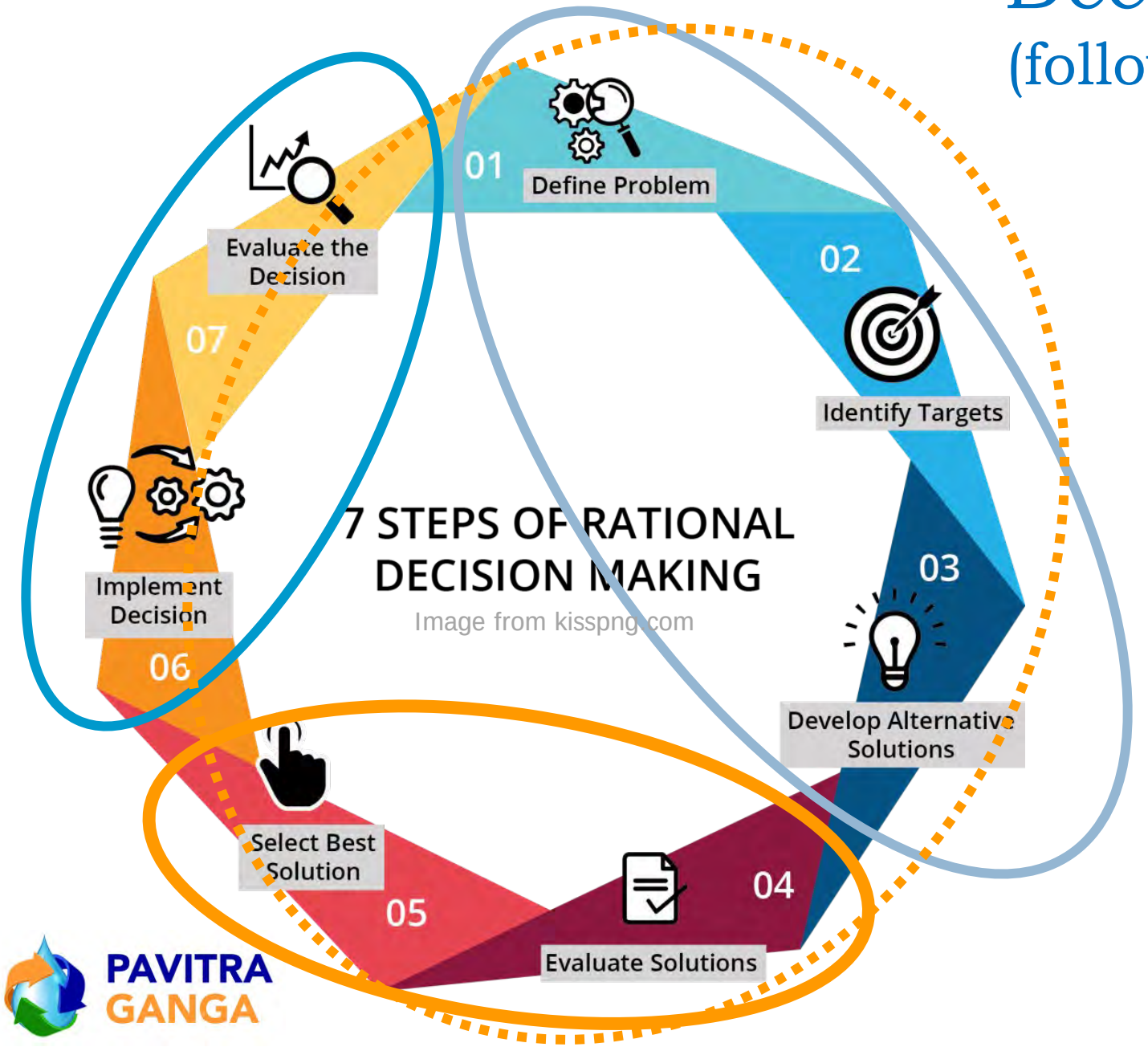


No decision can be better than the weakest link

PAVITRA GANGA

Spetzler, C., Winter, H., Meyer, J. 2016. *Decision Quality: Value Creation From Better Business Decisions.* Springer

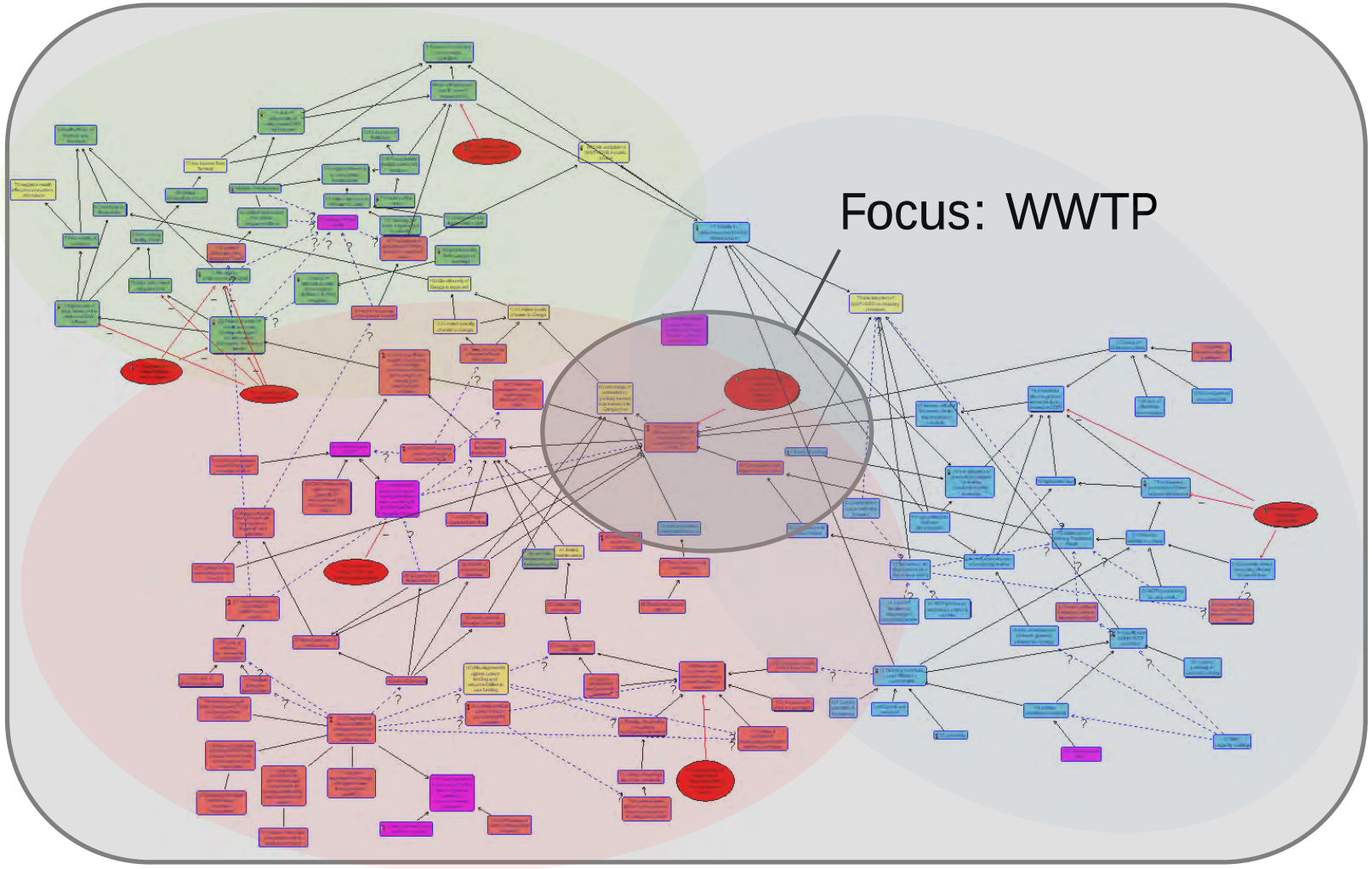
Decision making idealized
(following 'procedural rationality')



- Problem structuring methods (SODA, SSM, VFT, SCA...)
- Multi-criteria decision analysis (MCD/M...)
- Negotiation, planning, contracting, action, performance review

PAVITRA GANGA

(1) Choosing an appropriate problem frame



Focus: WW system (incl. production, transport, treatment, reuse)

Which problem to explore?

Who are the actors?

What are their resources?

Who wants what and why?

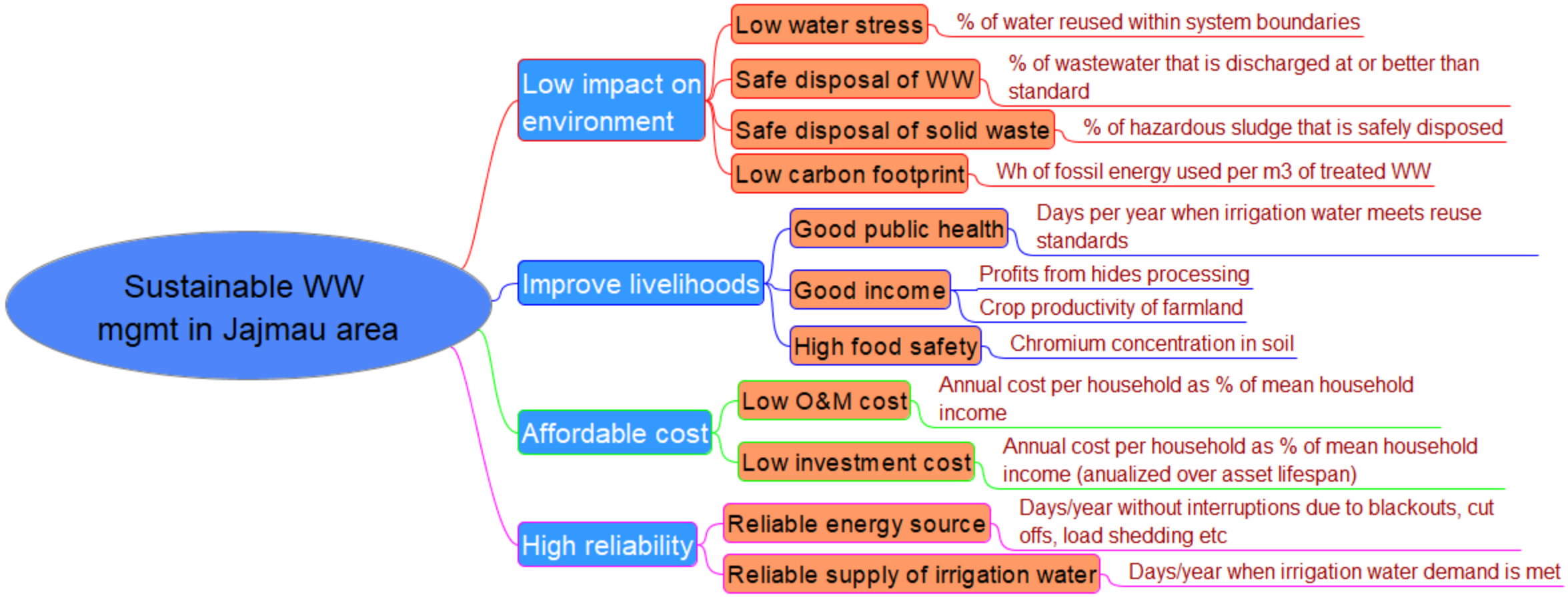
Here:

Zoom in or zoom out

-> Choice has consequences for actors, resources, values, alternatives at play!

PAVITRA GANGA

(2) Defining objectives and attributes



PAVITRA GANGA

(3) Identification of alternatives

Aim: creative alternatives that lead to best fulfillment of fundamental objectives while being comparable and complete

1. Define elements and characteristics of alternatives relevant to consider (combine creativity techniques and expertise)
2. Assemble promising alternatives systematically (e.g. using objectives, strategy generation tables, …)
3. Rough asessment of performance, improve candidate set, assess

→ Be rigorous. More alternatives mean more work without necessarily better results.

PAVITRA GANGA

Deciding which alternative solutions to include

#	Candidate alternative
1	Open covered drains and re-establish green corridors along urban surface water bodies
2	Build large treatment plants at the drain outlet to treat drain water before entering Blue river
3	Rehabilitate and expand centralized infrastructure to ensure delivery to treatment
4	Advanced, cheap treatment solutions for wastewater treatment to reuse quality
5	Transport system to bring treated wastewater to households and industry for reuse
6	Create awareness about environmental impact of illegal discharge to curb diffuse pollution
7	Public awareness raising campaigns to inform about water situation and to motivate reuse
8	Change financial incentives to make treated water reuse and energy recovery more attractive
9	Decentralized solutions to treat wastewater before discharge or reuse
10	Co-digestion of wastewater, faecal sludge and organic waste for energy recovery
11	Require and enable industries to implement zero liquid discharge (ZLD), ban all other industries
12	In-situ treatment of river water to ensure irrigation water quality before application to fields

- Check for links to focal problem
- Avoid decisions-within-decisions
- Screen relevance to stakeholders (resources, benefits)

PAVITRA GANGA

Deciding which candidate alternatives to include

#	Candidate alternative
1	**Open covered drains and re-establish green corridors along urban surface water bodies**
2	**Build large treatment plants at the drain outlet to treat drain water before entering Blue river**
3	**Rehabilitate and expand centralized infrastructure to ensure delivery to treatment**
4	**Advanced, cheap treatment solutions for wastewater treatment to reuse quality**
5	**Transport system to bring treated wastewater to households and industry for reuse**
~~6~~	~~Create awareness about environmental impact of illegal discharge to curb diffuse pollution~~
~~7~~	~~Public awareness raising campaigns to inform about water situation and to motivate reuse~~
~~8~~	~~Change financial incentives to make treated water reuse and energy recovery more attractive~~
9	**Decentralized solutions to treat wastewater before discharge or reuse**
? 10	Co-digestion of wastewater, faecal sludge and organic waste for energy recovery
? ~~11~~	~~Require and enable industries to implement zero liquid discharge (ZLD), ban all other industries~~
12	In-situ treatment of river water to ensure irrigation water quality before application to fields

PAVITRA GANGA

Define constituting factors and factor specifications

E.g. Using strategy generation tables (Howard 1988)

Assemble promising alternatives by combination

	1. Water source	2. Treatment technology	3. Receiver	…
a	Households	Primary	Farmers	…
b	Textile industry	Secondary	Blue river	…
…	…	…	…	…

A1: Households + primary treatment + Blue river

A2: Textile industry + secondary treatment + farmers

PAVITRA GANGA

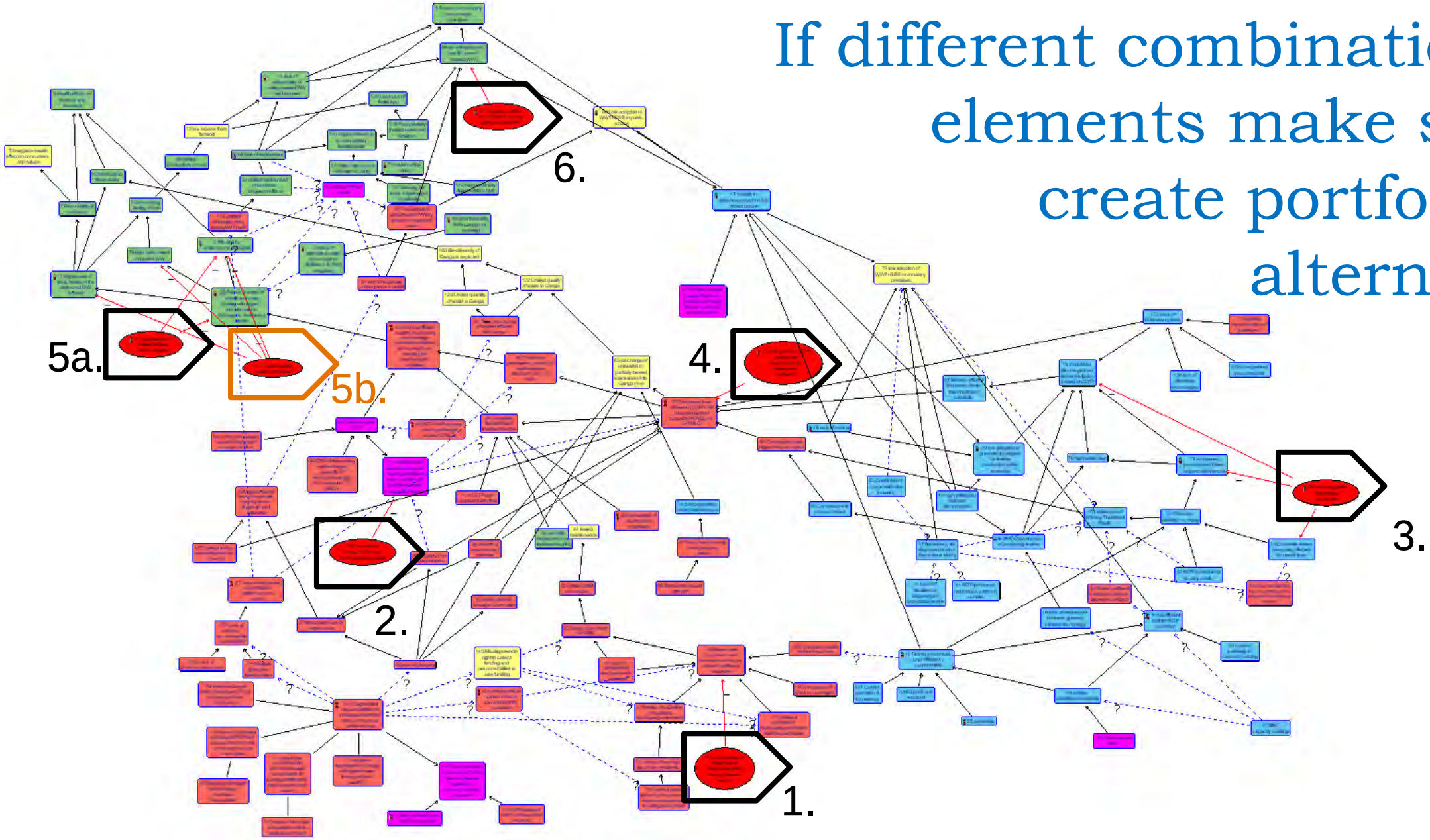
Use goals to guide alternative specification

	1. Water source	2. Treatment technology	3. Receiver	4. Transport
a	Households	Primary	Farmers	Lorries
b	Textile industry	Secondary	Blue river	Gravity pipes / drain
c	Businesses	Tertiary	Textile industry	Pressure pipes
d	Hospitals	Natural	Households	

«Cheap alternative» **1b+2d+3b+4b**
«Safe alternative» **1b+2c+3b+4b**
«Community alternative» **1a+2d+3d+4b**

PAVITRA GANGA

If different combinations of elements make sense: create portfolios of alternatives



Portfolio I = A1+A2+A3+A4+A5a+A6

Portfolio II = A1+A2+A3+A4+A5b+A6

PAVITRA GANGA

Assessing alternatives: different MCDA methods

Common aim: Support decision makers with complex decisions by combining impacts of alternatives and preferences about these

Multi-attribute utility/value theories («Americal school»), e.g.

- o Multi-attribute value theory - MAVT
- o Multi-attribute utility theory - MAUT
- o Analytical Hierarchy Process - AHP

Decision analysis, utility and probability theory, rationality axioms…

Outranking methods (French/ European School), e.g.

- o Elimination et choix traduisent la réalité (ELECTRE)
- o Preference ranking organization method for enrichment evaluation (PROMETHEE)

Social choice, set and graph theory, goal programming…

PAVITRA GANGA

(4) Evaluate solutions

Aim: Determine anticipated outcome of alternatives on objectives

-> Often most cost- / time-intensive MCDA task

1. Rough attribute assessment
2. Elimination of irrelevant alternatives
3. Focus effort on assessing remaining ones in detail

PAVITRA GANGA

The consequence table / decision matrix

	Attribute 1	Attribute 2	Attribute 3
A1	0.5	0.5	0.3
~~A2~~	~~0.7~~	~~0.3~~	~~0.5~~
A3	0	1	0.5
A4	1	0.4	1
A5	0.5	0.5	0.5

- A2 dominated by A4 → remove A2

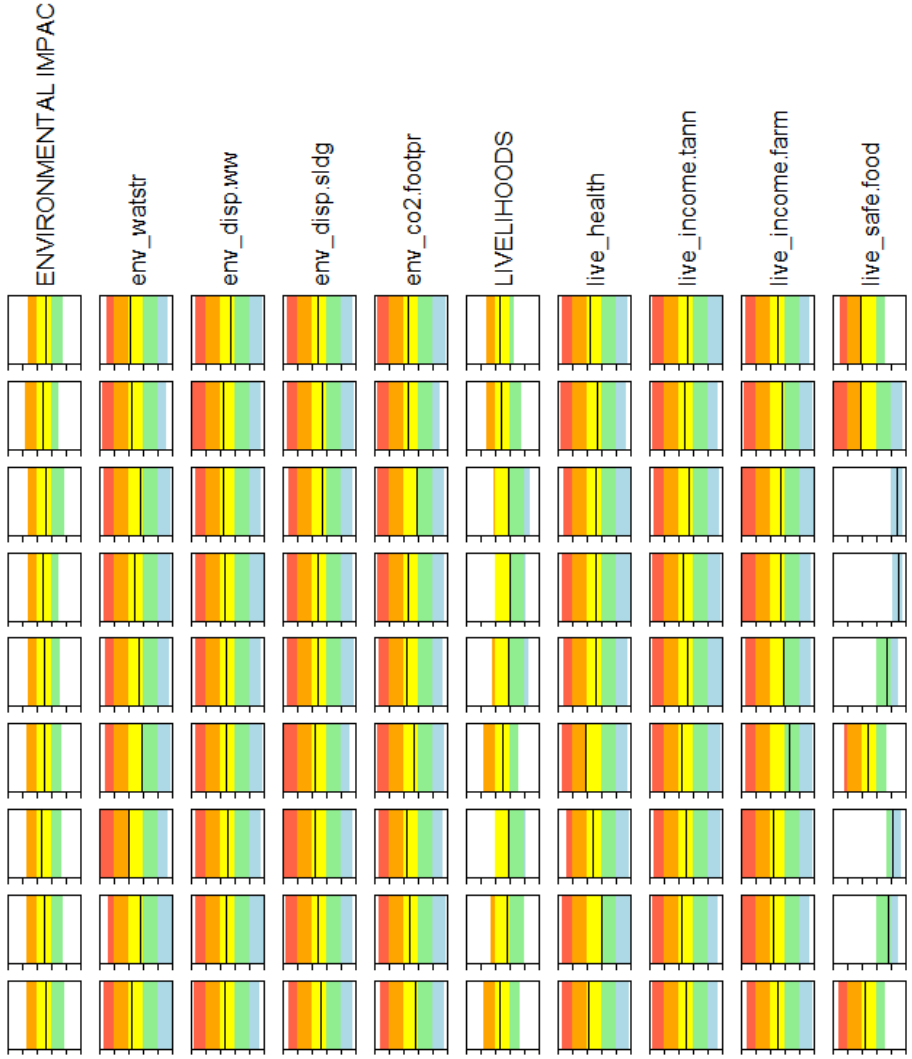
PAVITRA GANGA

Uncertainty matters!

Assessment of alternatives

Alternatives	ENVIRONMENTAL IMPACT	env_watstr	env_disp.ww	env_disp.sldg	env_co2.footpr	LIVELIHOODS	live_health	live_income.tann	live_income.farm	live_safe.food
0A-	.23	.41	0	0	.50	.22	0	.38	0	.49
0B-	.62	.60	.86	.50	.50	.56	.75	.50	.50	.50
1-V	.55	.50	.82	.38	.50	.50	.68	.38	.07	.89
2A-	.35	.41	0	0	1	.31	0	.25	.10	.90
2B-	.38	.41	.16	0	.96	.31	.14	.25	.08	.78
3A-	.42	.41	0	.25	1	.21	.11	.25	0	.49
4A-	.45	.50	.55	.25	.50	.40	.41	.25	.10	.85
4B-	.41	.50	.16	0	.96	.31	.14	.25	.06	.78
4C-	.61	.50	.55	.40	1	.36	.68	.25	0	.50

Attributes



PAVITRA GANGA

Scoring and ordering requires preference assessment

Preference elicitation - value trade-offs

- Data collection through interviews, survey or similar
- Mathematical description and modelling e.g. multi-attribute value function $V(A) = f(\Theta|x_A)$

V(A): overall value of alternative A [0…1]

f(): aggregator function

Θ: functional parameters, e.g. marginal values, 'weights'

$\mathbf{x_A}$: attribute outcome levels for alternative A

Simple additive model with three criteria: $V(A) = w_1 * v_1 + w_2 * v_2 + w_3 * v_3$

PAVITRA GANGA

Many types of preferences

Outcome trade-offs

How much of x for how much of y?

Time trade-offs

How much of x today for how much of y tomorrow?

Uncertainty trade-offs

How much of x with certainty for how much of y with uncertainty?

Distributional trade-offs

How much of x for me/us for how much of y for them?

PAVITRA GANGA

(5) Evaluate alternatives

E.g. for MAVT: compute an overall value, use insight to improve alternatives if possible and select best one (0: worst, 1: best possible)

	Attribute 1	Attribute 2	Attribute 3	Overall value
A1	0.5	0.5	0.3	0.43
~~A2~~	~~0.7~~	~~0.3~~	~~0.5~~	~~0.5~~
A3	0	1	0.5	0.5
A4	1	0.4	1	0.8
A5	0.5	0.5	0.5	0.5

For example

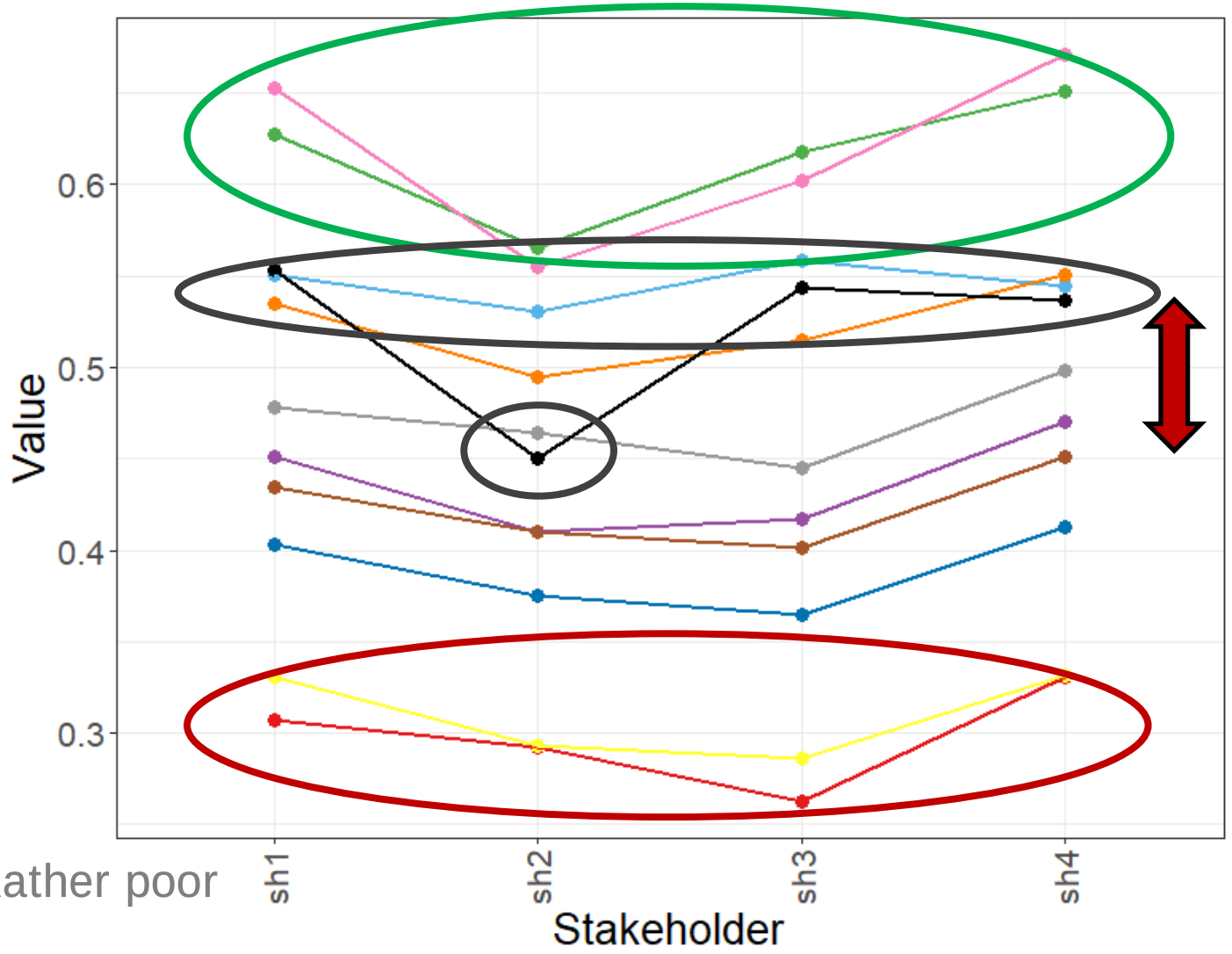
V(A1) = $w_1 * v_1 + w_2 * v_2 + w_3 * v_3 =$ **0.43**

V(A1) = $1/3 * 0.5 + 1/3 * 0.5 + 1/3 * 0.3 =$ **0.43**

PAVITRA GANGA

A multi-stakeholder example

Quite good



Rather poor

«Best» alternatives

Alternative with high conflict potential

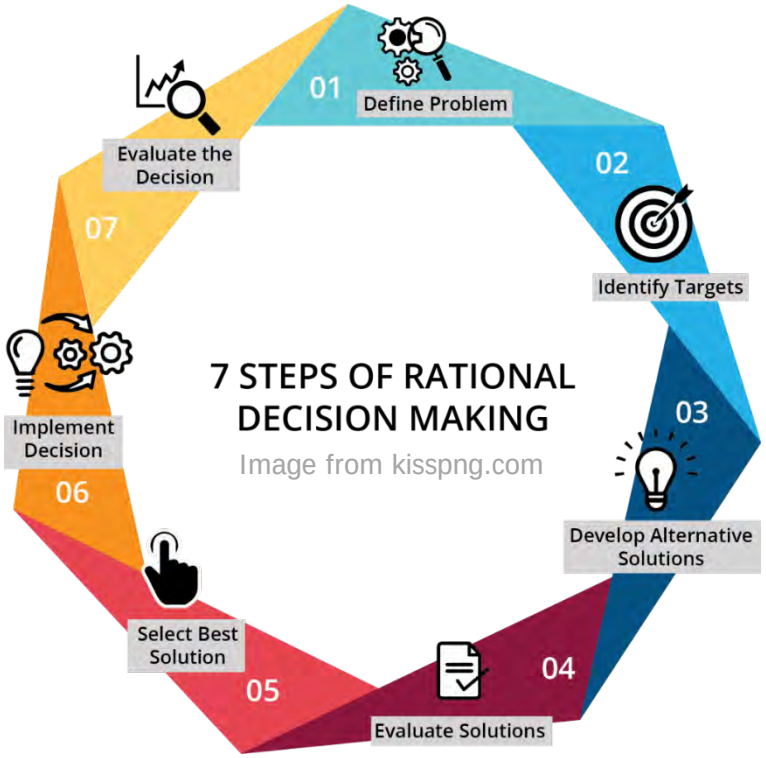
Status quo = worst option

Alternative
0A-Status quo
0B-New CETP-2022
1-Vegetable tanning
4C-Anaerobic co-digestion
5-Relocation of tanneries

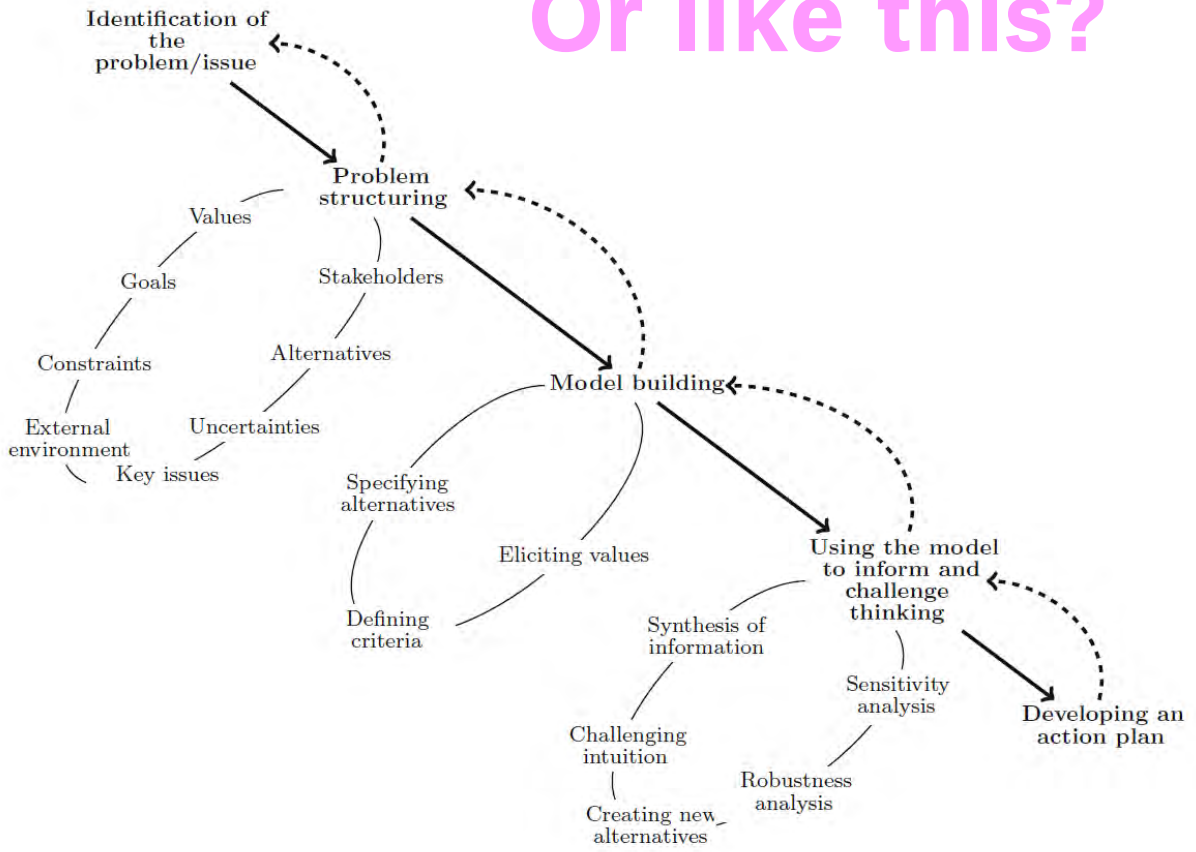
PAVITRA GANGA

Expect iteration. Adapt. Every process is different.

Like this?



Or like this?



Source: Belton V, Stewart TJ. Problem structuring for multiple criteria analysis. In: Ehrgott M, (ed.). Trends in Multiple Criteria Decision Analysis. International Series in Operations Research & Management Science 2010. p. 209 – 39.

PAVITRA GANGA

Take home messages

- Good decision making is key to good wastewater management
- MCDA methods are useful to address decision problems that are too complex for common sense
- Rigorous MCDA process enables good decisions. It cannot guarantee (regret-free) decision outcomes.
- Proper process embedding is critical to ensure decision quality and to manage actor dynamics

PAVITRA GANGA

Further reading

Decision making approaches and the need for decision support methods

- Bazerman, M. H., & Moore, D. A. (2013). Judgment in managerial decision making (8th ed ed.). Hoboken, NJ: Wiley.
- Schoemaker, J.H. and Russo, E. 1993. A pyramid of decision approaches. California Management Review 36(1) 9-31.

Decision quality

- Spetzler, C., Winter, H., Meyer, J. 2016. Decision Quality: Value Creation From Better Business Decisions. Springer

Problem structuring for MCDA

- Marttunen, M., Lienert, J., & Belton, V. (2017). Structuring problems for Multi-Criteria Decision Analysis in practice: A literature review of method combinations. European Journal of Operational Research, 263(1), 1-17.

Overview of MCDA history, methods and principles

- Greco, S., Ehrgott, M., Figueira, J.R. (eds.) 2016. Multiple Criteria Decision Analysis – State of the Art Surveys. International Series in Operations Research & Management Science. Springer. 2nd edition.

Portfolio decision analysis

- Salo, A., Keisler, J., & Morton, A. (Eds.). (2011). Portfolio decision analysis (Vol. 162). New York: Springer.

Applications in the water sector

Recommended

- Gregory, R., Failing, L., Harstone, M., Long, G., McDaniels, T., & Ohlson, D. (2012). Structured Decision Making - A practical guide to Environmental Management Choices (1st ed.): Wiley-Blackwell.
- Chhipi-Shrestha, G., Rodriguez, M., & Sadiq, R. (2019). Selection of sustainable municipal water reuse applications by multi-stakeholders using game theory. *Science of The Total Environment*, *650*, 2512-2526.
- Hajkowicz, S., & Collins, K. (2007). A review of multiple criteria analysis for water resource planning and management. Water Resources Management, 21(9), 1553-1566. doi:10.1007/s11269-006-9112-5
- Joubert, A., Stewart, T. J., & Eberhard, R. (2003). Evaluation of Water Supply Augmentation and Water Demand Management Options for the City of Cape Town. Journal of Multi-Criteria Decision Analysis(12), 17-25.

Own works

- Lienert, J., Scholten, L., Egger, C., & Maurer, M. (2015). Structured decision-making for sustainable water infrastructure planning and four future scenarios. EURO Journal on Decision Processes, 3(1-2), 107-140.
- Scholten, L., Reichert, P., Schuwirth, N., & Lienert, J. (2015). Tackling uncertainty in multi-criteria decision analysis-An application to water supply infrastructure planning. European Journal of Operational Research, 242(1), 243-260.
- Chacon-Hurtado, J. C., & Scholten, L. (2021). Decisi-o-rama: An open-source Python library for multi-attribute value/utility decision analysis. Environmental Modelling & Software, 135, 104890.
- Zabaleta, I., Mertenat, A., Scholten, L., Zurbrügg, C. SOWATT - Selecting Organic Waste Treatment Technologies. Guidebook for practitioners. Swiss Agency for Development and Cooperation and the Swiss State Secretariat for Economic Affairs
- Alhamed, H. (2020) Multi-criteria decision analysis for developing an integrated risk-based asset management framework - Demonstration on sewer asset management in Amsterdam. PDEng Dissertation. TU Delft.

PAVITRA GANGA

Thank you!

http://www.thisiscolossal.com/2017/06/polluted-water-popsicles/