

# **SUPPLEMENTARY MATERIAL**

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**Are objectives hierarchy related biases observed in practice?**

**A meta-analysis of environmental and energy applications of  
Multi-Criteria Decision Analysis**

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**Table S-1. Summary of the fifteen experiments and studies concerning structural and procedural biases related to the structure of objectives hierarchies and the weighting procedure.**

Authors	Year	Country	Case	Research topic	Weighting methods	Participants
Borcherding and von Winterfeldt	1988	USA	Nuclear waste depository	Structure of the hierarchy: location of the objective and splitting bias	Ratio, swing, trade-off	200 undergraduate psychology students
Cook and Stewart	1975	USA	Evaluation of students applying for financial aid and applicants of graduate school	Comparison of the accuracy of different weighting methods	E.g. direct point allocation, rating on a 100-point scale, paired comparisons, ratio	143 faculty and graduate student members of the University of Colorado
Fischer et al.	1987	USA	Pollution control measure	Consistency of utility functions for fundamental and proxy attributes	Multi-attribute utility preference model	24 graduate students of Carnegie-Mellon University's School of Urban and Public affairs
Fischer	1995	USA	Comparison of job offers	Range sensitivity of attributes	SMART, direct ratio, trade-off	52 undergraduate students
Hämäläinen and Alaja	2008	Finland	Water level regulation	Reduction of splitting bias through instruction and training	Swing	30 students of Helsinki University of Technology, four groups of stakeholders (ca 40), three experts
Jacobi and Hobbs	2007	USA	Electric system expansion	Mathematical model to estimate and correct attribute weighting biases	Direct point allocation	11 planners or midlevel executives from the Centerior Energy of Ohio
Lienert et al.	2016	Switzerland	Wastewater infrastructure	Preference stability over time with two weight elicitation methods	Swing, SMART/swing variant	249 Swiss citizens and 65 Eawag employees, experimental internet survey
Pöyhönen and Hämäläinen	1998	Finland	General	Influence of data analysis on observed biases (e.g. splitting bias)	Swing, ranking of objectives	Data from Borcherding and von Winterfeldt (1988), Weber et al. (1988) and from real lake regulation application
Pöyhönen and Hämäläinen	2000	Finland	Job selection; similar to Weber et al. (1988) and von Nitzsch and Weber (1991)	Impacts of participants' teaching on range insensitivity bias and splitting bias	Swing	42 students of Helsinki University of Technology
Pöyhönen et al.	2001	Finland, Netherlands	Selection of shop	Weighting biases (e.g. splitting bias) at the individual level	Swing	180 students of the Faculty of Economics at the University of Groningen
Pöyhönen and Hämäläinen	2001	Finland	Job or career alternatives	Convergent validity of five multi-attribute weighting methods	AHP, SMART, swing, direct point allocation, trade-off	407 students from different countries, internet experiment
Salo and Hämäläinen	1997	Finland	General	Impacts of the choice of ratio scales on weights and rank reversals	AHP, SMART	Theoretical
Stillwell et al.	1987	USA	Supply of energy	Comparison of hierarchical and non-hierarchical	SMART	37 undergraduates of the University of Southern California

Authors	Year	Country	Case	Research topic	Weighting methods	Participants
weights						
Von Nitzsch and Weber	1993	Germany	Job selection	Effect of attribute ranges on weights	Direct ratio, regression, bisection	138 graduate business and economics students
Weber et al.	1988	Germany	Job selection	Splitting bias	Ratio, swing, OTTO, conjoint	256 graduate business students

**Table S-2. Description of the selected cases and in which statistical analyses cases were included.**

Analyses refers to the meta-analysis in this paper, where

Analysis 1a: total number of lowest-level objectives and weight of the most important objective.

Analysis 1b: total number of lowest-level objectives and number of objectives getting very low weights.

Analysis 1c: mean global weights of the sub-objectives in the largest and smallest branch; analysis.

Analysis 1d: location of the most important objective in the objectives hierarchy.

Analysis 2a: Weights of environmental and economic objectives.

Analysis 2b: Weights of social and economic objectives.

Analysis 3: Lowest and highest weights of main objectives (equalising bias).

Authors	Year	Country of application	Application area	MCDA method	Source of weights	Number of weight profiles	Number of objectives <sup>1</sup>	Number of hierarchy levels	Analyses						
									1a	1b	1c	1d	2a	2b	3
Ahmad and Tahar	2014	Malaysia	Renewable energy	AHP	Unclear	1	12	2	v	v			v	v	
Akash et al.	1999	Jordan	Energy planning	AHP	Unclear	1	11 (5/6)	2	v	v					
Antunes et al.	2011	Portugal	Irrigation management	SMCE, AHP	Stakeholders	1	13 (6)	2	v	v					
Bana e Costa et al.	2004	Portugal	Flood control	MACBETH	Experts	1	16 (6)	3	v	v	v	v	v		
Bascetin	2007	Turkey	Mining	AHP	Experts	1	20	3	v	v			v	v	
Bojorquez-Tapia et al.	2005	Mexico	Environmental assessment	AHP	Experts	1	18 (6)	3	v	v					
Borsuk et al.	2007	Switzerland	Sanitation technology	MAVT	Stakeholders	1	9	2	v	v			v	v	
						1	9	2	v	v	v	v	v	v	
Brown et al.	2001	Tobago	Marine management	MCA, point allocation	Stakeholders	7	9 (3)	2	v	v			v	v	v
Buchholz et al.	2009	Uganda	Renewable energy	NAIADE	Stakeholders	1	9	2	v	v	v	v	v	v	v
Calizaya et al.	2010	Bolivia	Water resources management	AHP	Stakeholders	1	30	2	v	v					
Catron et al.	2013	USA	Renewable energy	ANP, AHP	Experts	1	12	2	v	v					
Chowdhury and Zaman	2009	Bangladesh	Stream rehabilitation	Weighted sum method	Stakeholders, experts	1	10	2	v	v	v	v	v	v	v
De Feo and De Gisi	2014	Italy	Waste management	AHP, SAW	Authors	1	13	3	v	v					
Ferretti and Comino	2015	Italy	Cultural and natural heritage	MAVT	Experts	6	7	1	v	v					
García de Jalón et al.	2013	Spain	Water resources management	AHP, Likert scale, equal weights	Stakeholders, Experts	2	17	3	v	v	v	v	v	v	v
Garfi et al.	2011	Brazil	Water management	AHP	Stakeholders	2	23	2	v	v					
Garmendia and Gamboa	2012	Spain (Basque Country)	Natural resources management	Simos, Outranking (CKYL)	Stakeholders	17	8	1	v	v					
Georgopoulou et al.	1997	Greece	Renewable energy	ELECTRE III	Decision-makers	8	15	5	v	v	v	v	v	v	v
Hahn	2014	USA	Energy sustainability	MAUT	Experts	1	12	3	v	v			v	v	
Haldi et al.	2002	Switzerland	Energy sustainability	Simos, PROMETHEE	Stakeholders	6	11	2	v	v	v	v	v	v	v
Herath	2004	Australia	Wetland management	AHP	Stakeholders	3	3	2	v	v					

Authors	Year	Country of application	Application area	MCDA method	Source of weights	Number of weight profiles	Number of objectives <sup>1</sup>	Number of hierarchy levels	Analyses					
									1a	1b	1c	1d	2a	2b
Hostmann et al.	2005	Switzerland	Stream rehabilitation	MAVT, Swing	Stake-holders	8	7	1	v	v				
Jämsén	2014	Finland	Transportation system	Swing	Stakeholders, authors	4	14	2	v	v	v	v	v	v
Joubert et al.	2003	South Africa	Water resources management	Swing	Experts	1	19	2	v	v			v	v
Karagiannidis and Moussiopoulos	1997	Greece	Waste management	ELECTRE III	Unclear	2	24	3	v	v	v	v		
Karjalainen et al.	2011	Finland	Migratory fish habitat	Swing	Stakeholders	25	10	3	v	v		v	v	v
Kodikara et al.	2010	Australia	Water supply	Simos, PROMETHEE	Stakeholders	8	8	2	v	v	v	v	v	v
Kowalski et al.	2009	Austria	Energy sustainability	Simos, PROMETHEE	Stakeholders	1	15	1	v	v				
Lee and Chan	2008	China (Hong Kong)	Urban development	AHP	Stakeholders, experts	2	18	2	v	v		v	v	
Lienert et al.	2011	Switzerland	Wastewater management	Reverse Swing method	Stakeholders	5	9	2	v	v	v	v	v	v
Lienert et al.	2016	Switzerland	Wastewater management	Swing, SMART/swing variant	Stakeholders, experts	2	10	2	v	v		v	v	
Linkov et al.	2006	USA	Contamination management	Percentage Weight, PROMETHEE	Stakeholders	4	4	1	v	v		v	v	
Lue and Colorni	2015	Italy	Transportation system	MAVT	Stakeholders	7	19	3	v	v	v	v	v	v
Marttunen and Hämäläinen	1995	Finland	Flood prevention	Swing, SMART	Stakeholders	2	15	3	v	v		v	v	
Marttunen et al.	2014	Finland	Urban development	Swing	Stakeholders, authors	4	26	3	v	v	v	v	v	v
Merrick and Garcia	2007	USA	Water management	Swing	Students, experts	1	33	3	v	v				
Mustajoki et al.	2011	Finland	Forest sustainability	Swing	Stakeholders	15	15	2	v	v	v	v		v
Neckles et al.	2014	USA	Wetland management	Weighted sum	Experts	1	10	3	v	v	v	v		
Nikodinoska et al.	2015	Italy	Renewable energy	AHP	Stakeholders	5	12	2	v	v				
Pascoe et al.	2009	Australia	Fishery	AHP	Stakeholders	8	14	3	v	v	v	v	v	v
Petersson and Giupponi	2004	Turkey	Hydropower	Swing	Authors	1	15	2	v	v		v	v	
Polatidis and Morales	2014	UK	Renewable energy	Simos, PROMETHEE	Students	5	13	1	v	v				
Prato	2003	USA	Stream ecosystem management	Concordance-discordance analysis, MAUT	Authors	1	6	2	v	v		v	v	
Pusnik and Susic	2014	Slovenia	Energy planning	AHP, MAUT, PROMETHEE	Stakeholders	1	6	2	v	v	v	v		
Rahman et al.	2015	Germany	Stream rehabilitation	PROMETHEE, AHP	Stakeholders	6	27	3	v	v	v	v		v
Regan et al.	2007	USA	Conservation planning	AHP	Experts	1	51	5	v	v				
Ribeiro et al.	2012	Portugal	Energy planning	Trade-off MAVT	Experts	2	13	1	v	v				

Authors	Year	Country of application	Application area	MCDA method	Source of weights	Number of weight profiles <sup>1</sup>	Number of objectives <sup>1</sup>	Number of hierarchy levels	Analyses						
									1a	1b	1c	1d	2a	2b	3
Rosso et al.	2014	Italy	Renewable energy	AHP	Stakeholders	1	31	2	v	v			v	v	
San Cristóbal	2011	Spain	Renewable energy	AHP, VIKOR	Authors	1	7	1	v	v					
Scholten et al.	2015	Switzerland	Water supply	MAUT, Swing	Stakeholders	10	30	5	v	v	v	v			v
Silva et al.	2010	Brazil	Watershed management	PROMETHEE	Decision makers	5	6	2	v	v			v	v	
Sorvari and Seppälä	2010	Finland	Contamination management, two cases	MAVT, SMART	Experts	1	14 15	3 3	v v	v v	v v	v v	v	v	
Stefanopoulos et al.	2013	Greece	Groundwater protection	MAVT	Stakeholders	5	5	1	v	v					
Straton et al.	2011	Australia	Water management	Compromise programming	Experts	1	16	2	v	v			v	v	
Tian et al.	2013	China	Renewable energy	AHP	Stakeholders, experts	1	14	3	v	v	v	v	v	v	
Tiwari et al.	1999	Thailand	Irrigation management	Compromise programming, AHP	Decision makers, Stakeholders	4	7	2	v	v			v		
von Stackelberg	2013	USA	Ecosystem management	MAVT	Authors	1	8	1	v	v					
Zardari et al.	2014	Malaysia	Watershed management	Swing SMART, SMARTER	Students	1	18	1	v	v					
Zheng et al.	2015 sub m.	Switzerland	Wastewater management	MAUT, swing	Stakeholders	10	19	3	v	v	v	v	v	v	

<sup>1</sup> Two numbers are presented in some cases. This is because the weights for the lowest-level objectives were not presented in the paper. In these cases we used the total number of lowest-level objectives in the hierarchy structure classification (Table 4, main text). The number in the bracket refers to the number of objectives for which weights were presented in the article. This number was used in the weight distribution analyses (analyses 1).

**Table S-3. Characteristics of the hierarchies in the selected cases**

Authors	Year	General structure of the objectives hierarchies Number of...					Hierarchy structure			Number of bottom level objectives belonging to different groups (mentioned where our own expert judgment)						
		Objec-tives <sup>1</sup>	Main objec-tives	Lowest-level objectives	Hier-archy levels	Alter-natives	Hierarchy depth <sup>2</sup>	Hierarchy breadth <sup>3</sup>	Eco-nomic	Tech-nical	Socio-eco-nomic	Social/Society	Environ-ment/Ecology	Risk	Other	
Ahmad and Tahar	2014	16	4	12	2	4	Medium	Broad	4	3	2	3				
Akash et al.	1999	13	2	11	2	5	Medium	Broad	5	3	1	1	3 (System's efficiency, System's safety, Availability of fuel)			
Antunes et al.	2011	19	6	13	2	6	Medium	Broad	2	5	2	2	2 (Water productivity,Irrigation consumptive use coefficient)			
Bana e Costa et al.	2004	24	3	16	3	3	Deep	Very broad		3	3	10				
Bascetin	2007	24	2	20	3	5	Deep	Very broad	2			9	9 (Cultural factors)			
Bojorquez-Tapia et al.	2005	28	6	18	3	3	Deep	Very broad			1	13	4 (Aviation hazards, physical)			
Borsuk et al. A (households) <sup>1</sup>	2007	13	4	9	2	8	Medium	Medium	2		2	2	3 (Personal quality)			
Borsuk et al. B (WWTP managers)	2007	12	3	9	2	8	Medium	Medium	4	3	0	2				
Brown et al.	2001	12	3	9	2	4	Medium	Medium	2		3	4				
Buchholz et al.	2009	12	3	9	2	2	Medium	Medium	2		4	2				
Calizaya et al.	2010	33	3	30	2	7	Medium	Very broad	10	1	10	10				
Catron et al.	2013	16	4	12	2	0	Medium	Broad					Difficult to classify using our classes (SWOT case)			
Chowdhury and	2009	14	4	10	2	3	Medium	Medium	2	2	4	2				

Authors	Year	General structure of the objectives hierarchies						Hierarchy structure						Number of bottom level objectives belonging to different groups (mentioned where our own expert judgment)			
		Objectives <sup>1</sup>	Main objectives	Lowest-level objectives	Hierarchy levels	Alternatives	Hierarchy depth <sup>2</sup>	Hierarchy breadth <sup>3</sup>	Economic	Technical	Socio-economic	Social/Society	Environment/Ecology	Risk	Other		
<b>Zaman</b>																	
Cristóbal, San	2011	7	7	7	1	13	Flat	Medium	2					1		4 (e.g. power, implementation period)	
De Feo and De Gisi	2014	22	7	13	3	4+2	Deep	Broad	2				3	3	6		Exp. Judg.
Ferretti and Comino	2015	7	7	7	1	10	Flat	Medium									Difficult to classify using our classes (SWOT case)
García de Jalón et al.	2013	22	3	17	3	8	Deep	Very broad	9				4	4			
Garfi et al.	2011	25	2	23	2	2	Medium	Very broad	0	12							12 ("general")
Garmendia and Gamboa	2012	8	8	8	1	8	Flat	Medium	2				2	3			1 (uncertainty), own judg.
Georgopoulou et al.	1997	23	2	15	5	8	Deep	Broad	2	3			2	8			2 (political)
Hahn	2014	20	3	12	3	9	Deep	Broad	6				4		2		
Haldi et al.	2002	14	3	11	2	9	Medium	Broad	2				2	7			
Herath	2004	7	3	3	2	3	Medium	Narrow	1				1	2			
Hostmann et al.	2005	7	7	7	1	5	Flat	Medium	2		2	1	1			1 (realization time) Exp. Judg.	
Jansen	2014	18	4	14	2	4	Medium	Broad	2				5				5 /traffic system), 2 (land use)

Authors	Year	General structure of the objectives hierarchies						Hierarchy structure						Number of bottom level objectives belonging to different groups (mentioned where our own expert judgment)					
		Objectives <sup>1</sup>	Main objectives	Lowest-level objectives	Hierarchy levels	Alternatives	Hierarchy depth <sup>2</sup>	Hierarchy breadth <sup>3</sup>	Economic	Technical	Socio-economic	Social/Society	Environment/Ecology	Risk	Other				
Joubert et al.	2003	24	5	19	2	23	Medium	Very broad	4	4	4		3				4 (political)		
Karagiannidis and Moussiopoulos	1997	30	5	24	3	5	Deep	Very broad	6	6	2		7			2 (resource conservation), 3 (environmental policy)			
Karjalainen et al.	2011	16	3	10	3	4	Deep	Medium	4			3	3						
Kodikara et al.	2010	12	4	8	2	0	Medium	Medium	2			1				4 (level of service), 1 (supply sustainability)			
Kowalski et al. Alternate weight scheme (local)	2009	15	15	15	1	5	Flat	Broad	1	1	5		4			1 (import independence), 1 (optimal use), 1 (security of supply), 1 (adapability)			
Lee and Chan	2008	21	3	18	2	0	Medium	Very broad	6			6	6						
Lienert et al.	2011	13	4	9	2	9 (selected from)	Medium	Medium	1			3	3			2 (feasibility)			

Authors	Year	General structure of the objectives hierarchies						Hierarchy structure						Number of bottom level objectives belonging to different groups (mentioned where our own expert judgment)					
		Objectives <sup>1</sup>	Main objectives	Lowest-level objectives	Hierarchy levels	Alternatives	Hierarchy depth <sup>2</sup>	Hierarchy breadth <sup>3</sup>	Economic	Technical	Socio-economic	Social/Society	Environment/Ecology	Risk	Other				
68)																			
Lienert et al.	2015 (subm.)	15	5	10	2	6	Medium	Medium	2	1	2	3	2						
Linkov et al.	2006	4	4	4	1	4	Flat	Narrow	1			1	2						
Lue and Colorni	2015	24	4	19	3	24	Deep	Very broad	10				5			3 (mobility), 1 (acceptability)			
Marttunen and Hämäläinen	1995	22	3	15	3	6	Deep	Broad	5			7	3						
Marttunen et al.	2014	38	4	26	3	4	Deep	Very broad	4			10	8			4 (image) Exp.judg.			
Merrick and Garcia	2007	42	2	33	3	2	Deep	Very broad				8	25			Exp. Judg.			
Mustajoki et al.	2011	21	6	15	2	5	Medium	Broad	6		4	3	1			1 (mutual understanding)			
Neckles et al.	2014	14	2	10	3	37	Deep	Medium	0				10						
Nikodinoska et al.	2015	16	4	12	2	0	Medium	Broad								SWOT, difficult to use MCDA classification			
Pascoe et al.	2009	22	4	14	3	0	Deep	Broad	3				5			4 (externalities), 2 (resource sustainability)			
Petersson and Giupponi	2007	18	3	15	2	3	Medium	Broad	5			5	5						
Polatidis and Morales	2014	13	13	13	1	4	Flat	Broad	5			4	3			1 (Energy)			
Prato	2003	9	3	6	2	5	Medium	Medium	2			2	2						

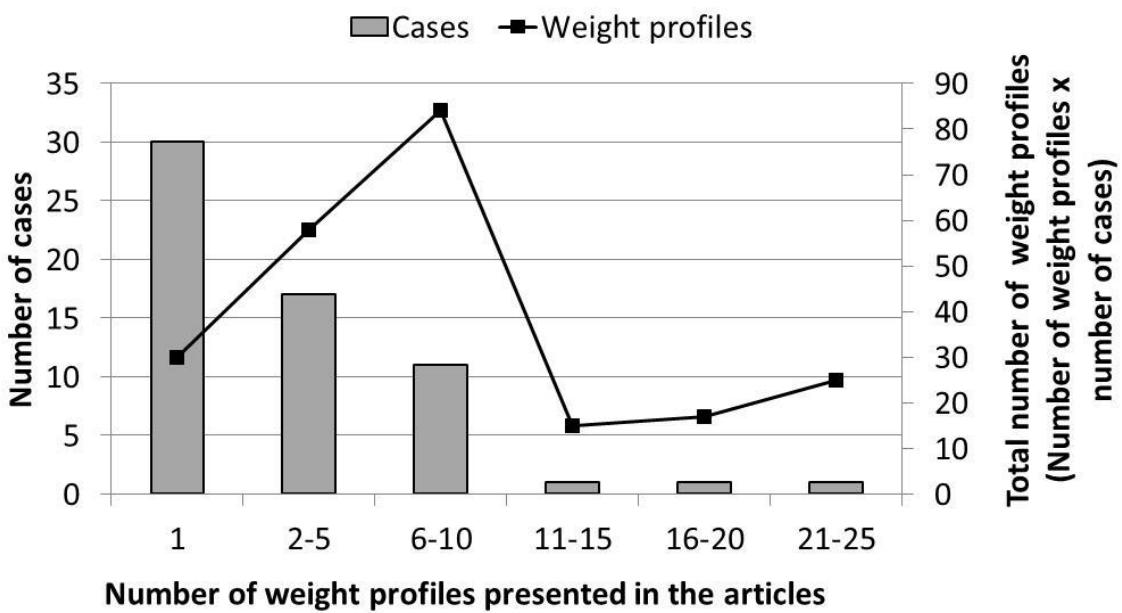
Authors	Year	General structure of the objectives hierarchies						Hierarchy structure		Number of bottom level objectives belonging to different groups (mentioned where our own expert judgment)					
		Objectives <sup>1</sup>	Main objectives	Lowest-level objectives	Hierarchy levels	Alternatives	Hierarchy depth <sup>2</sup>	Hierarchy breadth <sup>3</sup>	Economic	Technical	Socio-economic	Social/Society	Environment/Ecology	Risk	Other
Pusnik and Susic	2014	9	3	6	2	6	Medium	Medium	3		1		2		
Rahman et al.	2015	36	2	27	3	4	Deep	Very broad			17		10		
Regan et al.	2007	73	3	51	5	0	Deep	Very broad					51		
Ribeiro et al.	2012	13	13	13	1	5	Flat	Broad	4		2		4		3 (energy dependency, diversity of mix, rate of dispatchable)
Rosso et al.	2014	39	4	31	2	4	Medium	Very broad	8	8	7		8		They use term socio-political, those objectives included in Social category
Scholten et al.	2015	44	5	30	5	11	Deep	Very broad	2		8		2		18 (Water supply exp.judg.)
Silva et al.	2010	9	3	6	2	5	Medium	Medium	3	0	2		1		
Sorvari and Seppälä (shotgun shooting range)	2010	18	4	14	3	7	Deep	Broad	1		8		3		2
Sorvari and Seppälä (former gasoline station)	2010	19	4	15	3	9	Deep	Broad	1		9		3		2

Authors	Year	General structure of the objectives hierarchies						Hierarchy structure		Number of bottom level objectives belonging to different groups (mentioned where our own expert judgment)						
		Objectives <sup>1</sup>	Main objectives	Lowest-level objectives	Hierarchy levels	Alternatives	Hierarchy depth <sup>2</sup>	Hierarchy breadth <sup>3</sup>	Economic	Technical	Socio-economic	Social/Society	Environment/Ecology	Risk	Other	
Stefanopoulos et al.	2013	5	5	5	1	5	Flat	Narrow	1	1	1		1		1 (Measure efficiency) Exp. Judg.	
Straton et al.	2011	19	3	16	2	5	Medium	Very broad	3			7	6			
Tian et al.	2013	23	3	14	3	0	Deep	Broad	1			1	9		3 (Resource matching), exp. Judg.	
Tiwari et al.	1999	9	2	7	2	10	Medium	Medium	3				4			
von Stackelberg	2013	8	8	8	1	5	Flat	Medium	1			1	1		5 (Health risks), Exp.judg.	
Zardari et al.	2014	18	18	18	1	0	Flat	Very broad	1			8	7		1 (balancing ecological, economic and social); Some relate both env. and soc. Objectives; exp. judg.	
Zheng et al.	2016	29	5	19	3	13	Deep	Very broad	2			11	6		Equity exp. judg.	

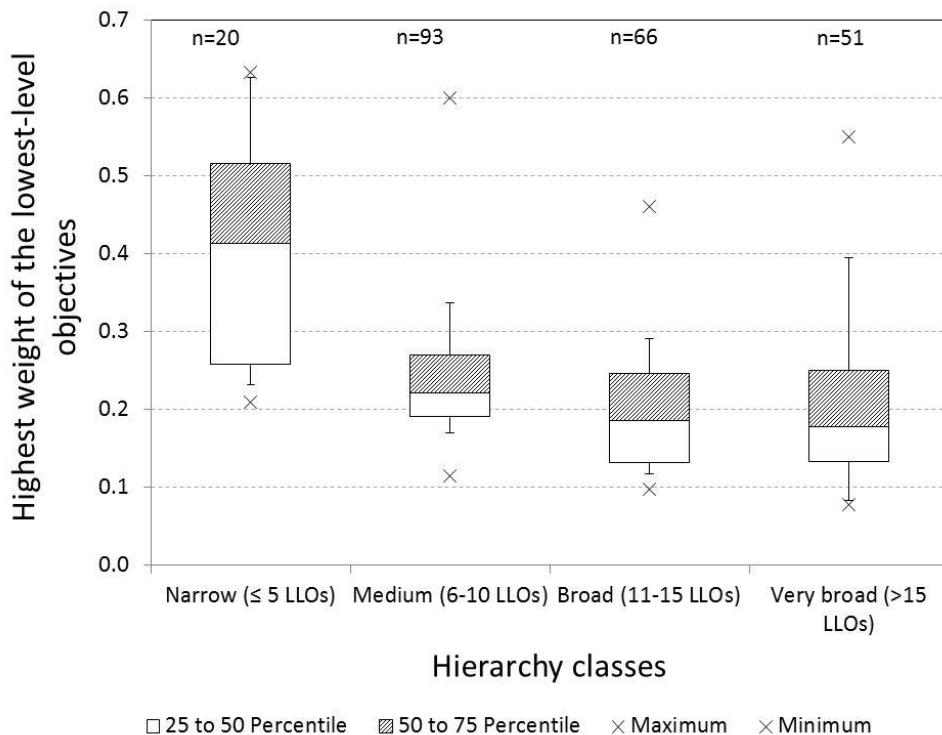
<sup>1</sup> Including all hierarchy levels, not overall objective (goal)

<sup>2</sup> Flat (1 level), Medium (2 levels), Deep ( $\geq 3$  levels)

<sup>3</sup> Narrow $\leq 5$  Bottom level objectives (BLOs), Medium = 6-10 BLOs, Broad = 11-15 BLOs , very broad  $>15$  BLOs



**Figure S-1.** Number of weight profiles in the cases (61 cases, n=number of weight profiles).



**Figure S-2.** Weights of the most important lowest-level objective in four hierarchy types. 10, 25, 50, 75 and 90 percentiles as well as minimum and maximum values are presented (n=230 weight profiles).

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