Chapter 13: Europe

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Table of Contents

SM13.1 Supplementary Material Supporting Section 13.2

Table SM13.1: Literature sources used in the assessment of feasibility and effectiveness of adaptation options for water systems in Europe. (Figure 13.6)

		References	**Effectiveness**	**Feasibility**					
Impact Type	**Adaptation Option**			Economic	Technological	Institutional	Socio-cultural	Ecological	Geophysical
Coastal and riverine flooding	Flood defences (Protect)	(Andersson-Sköld et al., 2015; Alfieri et al., 2016a; Bollinger and Dijkema, 2016; Bubeck et al., 2017; Bouwer et al., 2018; Del Bello, 2018; Metin et al., 2018; Pérez-Morales et al., 2018; Thacker et al., 2018; EEA, 2019c; EEA, 2019a; Straatsma et al., 2019; Dottori et al., 2020; Umgiesser, 2020; Vousdoukas et al., 2020)	(Andersson-Sköld et al., 2015; Alfieri et al., 2016a; Bollinger and Dijkema, 2016; Bouwer et al., 2018; Metin et al., 2018; Pérez-Morales et al., 2018; Thacker et al., 2018; EEA, 2019c; Straatsma et al., 2019; Dottori et al., 2020; Vousdoukas et al., 2020; Umgiesser et al., 2021)	(Alfieri et al., 2016a; Bollinger and Dijkema, 2016; Bouwer et al., 2018; Pérez-Morales et al., 2018; Thacker et al., 2018; EEA, 2019c; EEA, 2019a; Vousdoukas et al., 2020)	(Metin et al., 2018; Thacker et al., 2018; Straatsma et al., 2019; Vousdoukas et al., 2020)	(Bollinger and Dijkema, 2016; Bubeck et al., 2017; Thacker et al.; EEA, 2019c; EEA, 2019a)	(Alfieri et al., 2016a)	(Andersson-Sköld et al., 2015; Del Bello, 2018; Pérez-Morales et al., 2018; Vousdoukas et al., 2020)	(Del Bello, 2018; EEA, 2019a; Straatsma et al., 2019)
	Flood preparedness and Early warning plans (Protect/ Accommodate)	(Poussin et al., 2013; Kreibich et al., 2015; Pappenberger et al., 2015; Bubeck et al.,	(Poussin et al., 2013; Kreibich et al., 2015; Pappenberger et al., 2015; Bubeck et al.,	(Poussin et al., 2013; Kreibich et al., 2015; Pappenberger et al., 2015; Bubeck et al.,	(Poussin et al., 2013; Kreibich et al., 2015; Pappenberger et al., 2015; Bubeck et al.,	(Poussin et al., 2013; Kreibich et al., 2015; Pappenberger et al., 2015; Bubeck et al.,	(Poussin et al., 2013; Kreibich et al., 2015; Bubeck et al., 2017; Kreibich et al., 2017;	(Poussin et al., 2013; Kreibich et al., 2015; Pappenberger et al., 2015; Bubeck et al.,	(Poussin et al., 2013; Kreibich et al., 2015; Pappenberger et al., 2015; Bubeck et al., 2017;

		References	**Effectiveness**	**Feasibility**					
Impact Type	**Adaptation Option**			Economic	Technological	Institutional	Socio-cultural	Ecological	Geophysical
		2017; Kreibich et al., 2017; Pérez-Morales et al., 2018; Restemeyer et al., 2018; Varrani and Nones, 2018; Adedeji et al., 2019; Merz et al., 2020; Pirlone et al., 2020; Ribas et al., 2020; Kreibich et al., 2021)	2017; Kreibich et al., 2017; Pérez-Morales et al., 2018; Restemeyer et al., 2018; Varrani and Nones, 2018; Adedeji et al., 2019; Merz et al., 2020; Pirlone et al., 2020; Ribas et al., 2020; Kreibich et al., 2021)	2017; Kreibich et al., 2017; Pérez-Morales et al., 2018; Restemeyer et al., 2018; Varrani and Nones, 2018; Adedeji et al., 2019; Merz et al., 2020; Pirlone et al., 2020; Ribas et al., 2020; Kreibich et al., 2021)	2017; Kreibich et al., 2017; Pérez-Morales et al., 2018; Restemeyer et al., 2018; Varrani and Nones, 2018; Adedeji et al., 2019; Merz et al., 2020; Pirlone et al., 2020; Ribas et al., 2020; Kreibich et al., 2021)	2017; Kreibich et al., 2017; Pérez-Morales et al., 2018; Restemeyer et al., 2018; Varrani and Nones, 2018; Adedeji et al., 2019; Merz et al., 2020; Pirlone et al., 2020; Ribas et al., 2020; Kreibich et al., 2021)	Pérez-Morales et al., 2018; Restemeyer et al., 2018; Varrani and Nones, 2018; Adedeji et al., 2019; Merz et al., 2020; Pirlone et al., 2020; Ribas et al., 2020; Kreibich et al., 2021)	2017; Kreibich et al., 2017; Pérez-Morales et al., 2018; Restemeyer et al., 2018; Varrani and Nones, 2018; Adedeji et al., 2019; Merz et al., 2020; Pirlone et al., 2020; Ribas et al., 2020; Kreibich et al., 2021)	Kreibich et al., 2017; Pérez-Morales et al., 2018; Restemeyer et al., 2018; Varrani and Nones, 2018; Adedeji et al., 2019; Merz et al., 2020; Pirlone et al., 2020; Ribas et al., 2020; Kreibich et al., 2021)
	Planned Relocation (Retreat)	(Koerth et al., 2013; Harman et al., 2015; Thacker et al., 2018; Dachary-Bernard et al., 2019; Hofstede, 2019; Rey-Valette et al., 2019; Buser, 2020; Dottori et al., 2020; Lincke et al., 2020; Mayr et al., 2020; Seebauer and Winkler, 2020; Thaler, 2021)	(Koerth et al., 2013; Harman et al., 2015; Thacker et al., 2018; Dachary-Bernard et al., 2019; Hofstede, 2019; Rey-Valette et al., 2019; Buser, 2020; Dottori et al., 2020; Lincke et al., 2020; Mayr et al., 2020; Seebauer and Winkler, 2020; Thaler, 2021)	(Koerth et al., 2013; Harman et al., 2015; Thacker et al., 2018; Dachary-Bernard et al., 2019; Hofstede, 2019; Rey-Valette et al., 2019; Buser, 2020; Dottori et al., 2020; Lincke et al., 2020; Mayr et al., 2020; Seebauer and Winkler, 2020; Thaler, 2021)	(Koerth et al., 2013; Harman et al., 2015; Thacker et al., 2018; Dachary-Bernard et al., 2019; Hofstede, 2019; Rey-Valette et al., 2019; Dottori et al., 2020; Lincke et al., 2020; Mayr et al., 2020; Seebauer and Winkler, 2020; Thaler, 2021)	(Koerth et al., 2013; Harman et al., 2015; Thacker et al., 2018; Dachary-Bernard et al., 2019; Hofstede, 2019; Rey-Valette et al., 2019; Buser, 2020; Dottori et al., 2020; Lincke et al., 2020; Mayr et al., 2020; Seebauer and Winkler, 2020; Thaler, 2021)	(Koerth et al., 2013; Harman et al., 2015; Thacker et al., 2018; Dachary-Bernard et al., 2019; Hofstede, 2019; Rey-Valette et al., 2019; Buser, 2020; Dottori et al., 2020; Lincke et al., 2020; Mayr et al., 2020; Seebauer and Winkler, 2020; Thaler, 2021)	(Koerth et al., 2013; Harman et al., 2015; Thacker et al., 2018; Dachary-Bernard et al., 2019; Hofstede, 2019; Rey-Valette et al., 2019; Dottori et al., 2020; Lincke et al., 2020; Mayr et al., 2020; Seebauer and Winkler, 2020; Thaler, 2021)	(Koerth et al., 2013; Harman et al., 2015; Thacker et al., 2018; Dachary-Bernard et al., 2019; Hofstede, 2019; Rey-Valette et al., 2019; Buser, 2020; Dottori et al., 2020; Lincke et al., 2020; Mayr et al., 2020; Seebauer and Winkler, 2020; Thaler, 2021)

		References	**Effectiveness**	**Feasibility**					
Impact Type	**Adaptation Option**			Economic	Technological	Institutional	Socio-cultural	Ecological	Geophysical
	No-build zone, restrict new developments (Avoidance)	(Koerth et al., 2013; Andersson-Sköld et al., 2015; Harman et al., 2015; Thieken et al., 2016; Pérez-Morales et al., 2018; Thacker et al., 2018; Dachary-Bernard et al., 2019; Hofstede, 2019; Rey-Valette et al., 2019; Dottori et al., 2020; Lincke et al., 2020; Mayr et al., 2020; Thaler, 2021)	(Koerth et al., 2013; Andersson-Sköld et al., 2015; Harman et al., 2015; Thieken et al., 2016; Pérez-Morales et al., 2018; Thacker et al., 2018; Dachary-Bernard et al., 2019; Hofstede, 2019; Rey-Valette et al., 2019; Dottori et al., 2020; Lincke et al., 2020; Mayr et al., 2020; Thaler, 2021)	(Koerth et al., 2013; Andersson-Sköld et al., 2015; Harman et al., 2015; Thieken et al., 2016; Pérez-Morales et al., 2018; Thacker et al., 2018; Dachary-Bernard et al., 2019; Hofstede, 2019; Rey-Valette et al., 2019; Dottori et al., 2020; Lincke et al., 2020; Mayr et al., 2020; Thaler, 2021)	(Koerth et al., 2013; Andersson-Sköld et al., 2015; Harman et al., 2015; Thieken et al., 2016; Pérez-Morales et al., 2018; Thacker et al., 2018; Dachary-Bernard et al., 2019; Hofstede, 2019; Rey-Valette et al., 2019; Dottori et al., 2020; Lincke et al., 2020; Mayr et al., 2020; Thaler, 2021)	(Koerth et al., 2013; Andersson-Sköld et al., 2015; Harman et al., 2015; Thieken et al., 2016; Pérez-Morales et al., 2018; Thacker et al., 2018; Dachary-Bernard et al., 2019; Hofstede, 2019; Rey-Valette et al., 2019; Dottori et al., 2020; Lincke et al., 2020; Mayr et al., 2020; Thaler, 2021)		(Koerth et al., 2013; Andersson-Sköld et al., 2015; Harman et al., 2015; Thieken et al., 2016; Pérez-Morales et al., 2018; Thacker et al., 2018; Dachary-Bernard et al., 2019; Hofstede, 2019; Rey-Valette et al., 2019; Dottori et al., 2020; Lincke et al., 2020; Mayr et al., 2020; Thaler, 2021)	
	Flood insurance (Supporting)	(Koerth et al., 2013; Poussin et al., 2013; Keskitalo et al., 2014; Paudel et al., 2015; Penning-Rowsell and Priest, 2015; Surminski et al., 2015; Hudson et al., 2016; O'Hare et al.,	(Koerth et al., 2013; Poussin et al., 2013; Keskitalo et al., 2014; Paudel et al., 2015; Penning-Rowsell and Priest, 2015; Surminski et al., 2015; Hudson et al.,	(Koerth et al., 2013; Poussin et al., 2013; Keskitalo et al., 2014; Paudel et al., 2015; Penning-Rowsell and Priest, 2015; Surminski et al., 2015; Hudson et al., 2016; O'Hare et al., 2016;	(Koerth et al., 2013; Poussin et al., 2013; Keskitalo et al., 2014; Paudel et al., 2015; Penning-Rowsell and Priest, 2015; Surminski et al., 2015; Hudson et al., 2016; O'Hare et al., 2016;	(Koerth et al., 2013; Poussin et al., 2013; Keskitalo et al., 2014; Paudel et al., 2015; Penning-Rowsell and Priest, 2015; Surminski et al., 2015; Hudson et al., 2016; O'Hare et al., 2016;	(Koerth et al., 2013; Poussin et al., 2013; Keskitalo et al., 2014; Paudel et al., 2015; Penning-Rowsell and Priest, 2015; Surminski et al., 2015; Hudson et al., 2016; O'Hare et al., 2016;	(Koerth et al., 2013; Poussin et al., 2013; Keskitalo et al., 2014; Paudel et al., 2015; Penning-Rowsell and Priest, 2015; Surminski et al., 2015; Hudson et al., 2016; O'Hare et al., 2016;	

		References	**Effectiveness**	**Feasibility**					
Impact Type	**Adaptation Option**			Economic	Technological	Institutional	Socio-cultural	Ecological	Geophysical
		2016; Suykens et al., 2016; Surminski and Thieken, 2017; Hanger et al., 2018; Hudson, 2018; Surminski, 2018)	2016; O'Hare et al., 2016; Suykens et al., 2016; Surminski and Thieken, 2017; Hanger et al., 2018; Hudson, 2018; Surminski, 2018)	Suykens et al., 2016; Surminski and Thieken, 2017; Hanger et al., 2018; Hudson, 2018; Surminski, 2018)	Suykens et al., 2016; Surminski and Thieken, 2017; Hanger et al., 2018; Hudson, 2018; Surminski, 2018)	Suykens et al., 2016; Surminski and Thieken, 2017; Hanger et al., 2018; Hudson, 2018; Surminski, 2018)	Suykens et al., 2016; Surminski and Thieken, 2017; Hanger et al., 2018; Hudson, 2018; Surminski, 2018)	Suykens et al., 2016; Surminski and Thieken, 2017; Hanger et al., 2018; Hudson, 2018; Surminski, 2018)	
Coastal flooding	Wet and dry proofing (Accommodate)	(Botzen et al., 2013; Poussin et al., 2015; Stojanov et al., 2015; Bouwer et al., 2018; Hudson et al., 2019)	(Botzen et al., 2013; Poussin et al., 2015; Stojanov et al., 2015; Bouwer et al., 2018; Hudson et al., 2019)	(Botzen et al., 2013; Poussin et al., 2015; Stojanov et al., 2015; Bouwer et al., 2018; Hudson et al., 2019)		(Botzen et al., 2013; Poussin et al., 2015; Stojanov et al., 2015; Bouwer et al., 2018; Hudson et al., 2019)	(Botzen et al., 2013; Stojanov et al., 2015)		
	Sediment based (e.g. nourishment) (Protect)	(Temmerman et al., 2013; Parkinson and Ogurcak, 2018; de Schipper et al., 2021; Staudt et al., 2021)	(Campos et al., 2016)	(Temmerman et al., 2013; Campos et al., 2016; de Schipper et al., 2021; Staudt et al., 2021)	(Temmerman et al., 2013; Campos et al., 2016; de Schipper et al., 2021; Staudt et al., 2021)	(Campos et al., 2016; de Schipper et al., 2021; Staudt et al., 2021)	(Temmerman et al., 2013; de Schipper et al., 2021; Staudt et al., 2021)	(Temmerman et al., 2013; Parkinson and Ogurcak, 2018; de Schipper et al., 2021; Staudt et al., 2021)	(Parkinson and Ogurcak, 2018; Staudt et al., 2021)
	Ecosystem based (e.g. wetlands, dunes) (Protect)	(Temmerman et al., 2013; Narayan et al., 2016; Vuik et al., 2019)	(Temmerman et al., 2013; Narayan et al., 2016; Vuik et al., 2019) 2	(Temmerman et al., 2013; Narayan et al., 2016; Vuik et al., 2019)	(Temmerman et al., 2013; Narayan et al., 2016; Vuik et al., 2019)			(Temmerman et al., 2013; Narayan et al., 2016; Vuik et al., 2019)	(Temmerman et al., 2013; Vuik et al., 2019)
Riverine flooding	Wet and dry proofing (Accommodate)	(Botzen et al., 2013; Hudson et al., 2014; Kreibich et al., 2015; Poussin et	(Hudson et al., 2014; Kreibich et al., 2015; Poussin et al., 2015; Jones et	(Osberghaus, 2017; Thacker et al., 2018)	(Botzen et al., 2013; Hudson et al., 2014; Kreibich et al., 2015; Poussin et	(Botzen et al., 2013; Hudson et al., 2014; Kreibich et al., 2015; Poussin et	(Botzen et al., 2013; Stojanov et al., 2015; Osberghaus, 2017)		(Jones et al., 2017)

		References	**Effectiveness**	**Feasibility**					
Impact Type	**Adaptation Option**			Economic	Technological	Institutional	Socio-cultural	Ecological	Geophysical
		al., 2015; Stojanov et al., 2015; Jones et al., 2017; Osberghaus, 2017; Bouwer et al., 2018; Salinas-Rodriguez et al., 2018; Thacker et al., 2018; Haer et al., 2019; Hudson et al., 2019; Sairam et al., 2019)	al., 2017; Osberghaus, 2017; Bouwer et al., 2018; Salinas-Rodriguez et al., 2018; Thacker et al., 2018; Haer et al., 2019; Hudson et al., 2019; Sairam et al., 2019)		al., 2015; Stojanov et al., 2015; Jones et al., 2017; Osberghaus, 2017; Bouwer et al., 2018; Salinas-Rodriguez et al., 2018; Thacker et al., 2018; Haer et al., 2019; Hudson et al., 2019; Sairam et al., 2019)	al., 2015; Stojanov et al., 2015; Jones et al., 2017; Osberghaus, 2017; Bouwer et al., 2018; Salinas-Rodriguez et al., 2018; Thacker et al., 2018; Haer et al., 2019; Hudson et al., 2019; Sairam et al., 2019)			
Riverine flooding	Ecosystem based (e.g. floodplain restoration, widening riverbed) (Protect)	(Asselman and Klijn, 2016; Dadson et al., 2017; Straatsma et al., 2019; Dottori et al., 2020; European Commission, 2020)	(Dadson et al., 2017; Straatsma et al., 2019; Dottori et al., 2020)	(Straatsma et al., 2019; Dottori et al., 2020)	(Straatsma et al., 2019)		(Straatsma et al., 2019; Dottori et al., 2020)		(Asselman and Klijn, 2016; Dadson et al., 2017; Straatsma et al., 2019; Dottori et al., 2020; European Commission, 2020)
	Retention and diversion (Accommodate)	(Gocht and Meon, 2016; Dadson et al., 2017; Verkerk et al., 2017; Dottori et al., 2020)	(Gocht and Meon, 2016; Dadson et al., 2017; Verkerk et al., 2017; Dottori et al., 2020)	(Gocht and Meon, 2016; Verkerk et al., 2017)	(Gocht and Meon, 2016; Verkerk et al., 2017)		(Verkerk et al., 2017; Dottori et al., 2020)	(Verkerk et al., 2017; Dottori et al., 2020)	
Pluvial flooding	Green roofs (Accommodate)	(Andersson-Sköld et al., 2015; Arnbjerg-Nielsen et al.,	(Andersson-Sköld et al., 2015; Zölch et al., 2017; Liu	(Andersson-Sköld et al., 2015; Zölch et al., 2017; Liu et	(European Commission, 2020)		(Zölch et al., 2017)	(Andersson-Sköld et al., 2015; Zölch et al., 2017)	(Andersson-Sköld et al., 2015; Zölch et al., 2017; Liu et al.,

		References	**Effectiveness**	**Feasibility**					
Impact Type	**Adaptation Option**			Economic	Technological	Institutional	Socio-cultural	Ecological	Geophysical
		2015; Zölch et al., 2017; Liu et al., 2018; Maragno et al., 2018; Salinas-Rodriguez et al., 2018; Babovic and Mijic, 2019; Ribas et al., 2020)	et al., 2018; Babovic and Mijic, 2019)	al., 2018; Babovic and Mijic, 2019)					2018; European Commission, 2020)
	Retention parks (Accommodate)	(Andersson-Sköld et al., 2015; Arnbjerg-Nielsen et al., 2015; Zölch et al., 2017; Liu et al., 2018; Maragno et al., 2018; Salinas-Rodriguez et al., 2018; Babovic and Mijic, 2019; Ribas et al., 2020)	(Andersson-Sköld et al., 2015; Arnbjerg-Nielsen et al., 2015; Maragno et al., 2018; Salinas-Rodriguez et al., 2018; Ribas et al., 2020)		(Maragno et al., 2018; Ribas et al., 2020)		(Andersson-Sköld et al., 2015; Maragno et al., 2018)	(Andersson-Sköld et al., 2015; Arnbjerg-Nielsen et al., 2015; Maragno et al., 2018; Salinas-Rodriguez et al., 2018; Ribas et al., 2020)	(Andersson-Sköld et al., 2015; Arnbjerg-Nielsen et al., 2015; Maragno et al., 2018; Salinas-Rodriguez et al., 2018; Ribas et al., 2020)
	Update drainage system and pumps (Accommodate)	(Skougaard Kaspersen et al., 2017; Liu and Jensen, 2018; EEA, 2020b; Ribas et al., 2020)	(Skougaard Kaspersen et al., 2017)	(Skougaard Kaspersen et al., 2017; Liu and Jensen, 2018; EEA, 2020b; Ribas et al., 2020)	(Ribas et al., 2020)	(Liu and Jensen, 2018; EEA, 2020b)	(EEA, 2020b)	(EEA, 2020b)	(Liu and Jensen, 2018; EEA, 2020b)
Water scarcity	Supply - Storage (reservoirs)	(Papadaskalopoulou et al., 2015b; Kingsborough et al., 2016;	(Papadaskalopoulou et al., 2015b; Kingsborough et al., 2016;	(Papadaskalopoulou et al., 2015b; Kingsborough et al., 2016; Varela-Ortega et	(Papadaskalopoulou et al., 2015b; Varela-Ortega et al., 2016; Verkerk et al.,	(Papadaskalopoulou et al., 2015b; Kingsborough et al., 2016; Varela-Ortega et	(Papadaskalopoulou et al., 2015b; Verkerk et al., 2017)	(Papadaskalopoulou et al., 2015b; Varela-Ortega et al., 2016; Di Baldassarre et	(Papadaskalopoulou et al., 2015b; Kingsborough et al., 2016; Bucak et al., 2017; Di

		References	**Effectiveness**	**Feasibility**					
Impact Type	**Adaptation Option**			Economic	Technological	Institutional	Socio-cultural	Ecological	Geophysical
		Varela-Ortega et al., 2016; Bucak et al., 2017; Verkerk et al., 2017; Di Baldassarre et al., 2018; Santos et al., 2018; Garnier and Holman, 2019)	Varela-Ortega et al., 2016; Bucak et al., 2017; Verkerk et al., 2017; Di Baldassarre et al., 2018; Garnier and Holman, 2019)	al., 2016; Bucak et al., 2017; Verkerk et al., 2017; Di Baldassarre et al., 2018; Garnier and Holman, 2019)	2017; Garnier and Holman, 2019)	al., 2016; Thacker et al., 2018; Garnier and Holman, 2019)		al., 2018; Santos et al., 2018; Garnier and Holman, 2019)	Baldassarre et al., 2018; Santos et al., 2018; Garnier and Holman, 2019)
	Supply - Water diversion and transfer	(Fleskens et al., 2013; Collet et al., 2015; Papadaskalopoulou et al., 2015b; Garnier and Holman, 2019)	(Fleskens et al., 2013; Collet et al., 2015; Papadaskalopoulou et al., 2015b)	(Fleskens et al., 2013; Collet et al., 2015)	(Fleskens et al., 2013; Collet et al., 2015; Papadaskalopoulou et al., 2015b)	(Fleskens et al., 2013; Collet et al., 2015; Papadaskalopoulou et al., 2015b; Garnier and Holman, 2019)	(Fleskens et al., 2013; Papadaskalopoulou et al., 2015b)	(Papadaskalopoulou et al., 2015b; Garnier and Holman, 2019)	(Collet et al., 2015)
	Supply - Desalinisation	(Papadaskalopoulou et al., 2015b; Kingsborough et al., 2016; Garnier and Holman, 2019; Morote et al., 2019; De Roo et al., 2020)	(Papadaskalopoulou et al., 2015b; Kingsborough et al., 2016; Garnier and Holman, 2019; Morote et al., 2019)	(Papadaskalopoulou et al., 2015b; Garnier and Holman, 2019; Morote et al., 2019)	(Papadaskalopoulou et al., 2015b; Kingsborough et al., 2016; Garnier and Holman, 2019; Morote et al., 2019)	(Papadaskalopoulou et al., 2015b; Kingsborough et al., 2016; Garnier and Holman, 2019; Morote et al., 2019)	(Morote et al., 2019)	(Papadaskalopoulou et al., 2015b; Morote et al., 2019) Morete et al., 2019; Papadaskalopoulou et al., 2015	(Garnier and Holman, 2019; Morote et al., 2019)
	Supply - Water reuse	(Papadaskalopoulou et al., 2015b; Kingsborough et al., 2016;Morote, 2019; De Roo et al., 2020)	(Papadaskalopoulou et al., 2015b; Kingsborough et al., 2016;Morote, 2019; De Roo et al., 2020)	(Papadaskalopoulou et al., 2015b; Morote et al., 2019)	(Papadaskalopoulou et al., 2015b; Kingsborough et al., 2016;Morote, 2019; De Roo et al., 2020)	(Papadaskalopoulou et al., 2015b; Kingsborough et al., 2016;Morote, 2019)	(Papadaskalopoulou et al., 2015b; Morote et al., 2019)	(Papadaskalopoulou et al., 2015b; Morote et al., 2019)	(Morote et al., 2019)

		References	**Effectiveness**	**Feasibility**					
Impact Type	**Adaptation Option**			Economic	Technological	Institutional	Socio-cultural	Ecological	Geophysical
	Demand - Water saving and efficiency	(Collet et al., 2015; Papadaskalopoulou et al., 2015b; van Duinen et al., 2015; Fader et al., 2016; Kingsborough et al., 2016; Varela-Ortega et al., 2016; Rey et al., 2017; Verkerk et al., 2017; Iglesias et al., 2018; Manouseli et al., 2018; Papadimitriou et al., 2019; De Roo et al., 2020)	(Collet et al., 2015; Papadaskalopoulou et al., 2015b; Fader et al., 2016; Kingsborough et al., 2016; Varela-Ortega et al., 2016; Iglesias et al., 2018; Manouseli et al., 2018; Papadimitriou et al., 2019; De Roo et al., 2020)	(Papadaskalopoulou et al., 2015b; van Duinen et al., 2015; Fader et al., 2016; Kingsborough et al., 2016; Varela-Ortega et al., 2016; Rey et al., 2017; Iglesias et al., 2018; Manouseli et al., 2018)	(Collet et al., 2015; Papadaskalopoulou et al., 2015b; van Duinen et al., 2015; Fader et al., 2016; Varela-Ortega et al., 2016; Rey et al., 2017; Verkerk et al., 2017; Iglesias et al., 2018; Manouseli et al., 2018)	(Collet et al., 2015; Papadaskalopoulou et al., 2015b; Varela-Ortega et al., 2016; Verkerk et al., 2017; Papadimitriou et al., 2019)	(Collet et al., 2015; Papadaskalopoulou et al., 2015b; Manouseli et al., 2018)	(van Duinen et al., 2015; Fader et al., 2016; Varela-Ortega et al., 2016; Verkerk et al., 2017; Iglesias et al., 2018; Papadimitriou et al., 2019)	(van Duinen et al., 2015; Papadimitriou et al., 2019)
	Demand - Regulate distribution	(Papadaskalopoulou et al., 2015b; Manouseli et al., 2018; Garnier and Holman, 2019; Teotónio et al., 2020)	(Papadaskalopoulou et al., 2015b; Manouseli et al., 2018; Garnier and Holman, 2019; Teotónio et al., 2020)	(Papadaskalopoulou et al., 2015b; Garnier and Holman, 2019; Teotónio et al., 2020)	(Manouseli et al., 2018; Garnier and Holman, 2019)	(Papadaskalopoulou et al., 2015b; Manouseli et al., 2018; Garnier and Holman, 2019; Teotónio et al., 2020)	(Papadaskalopoulou et al., 2015b)		(Manouseli et al., 2018; Garnier and Holman, 2019; Teotónio et al., 2020)
	Demand - Economic instruments	(Kayaga and Smout, 2014; Wimmer et al., 2014; Esteve et al., 2015; Kahil et al., 2015;	(Kayaga and Smout, 2014; Wimmer et al., 2014; Esteve et al., 2015; Kahil et al.,	(Kayaga and Smout, 2014; Esteve et al., 2015; Kahil et al., 2015; Papadaskalopoul	(Wimmer et al., 2014; Esteve et al., 2015; Kahil et al., 2015; Papadaskalopoulou et al., 2015b;	(Esteve et al., 2015; Kahil et al., 2015; Papadaskalopoulou et al., 2015b; Varela-Ortega et	(Kayaga and Smout, 2014; Esteve et al., 2015; Kahil et al., 2015;	(Esteve et al., 2015; Kahil et al., 2015; Varela-Ortega et al., 2016)	(Esteve et al., 2015)

		References	**Effectiveness**	**Feasibility**					
Impact Type	**Adaptation Option**			Economic	Technological	Institutional	Socio-cultural	Ecological	Geophysical
		Papadaskalopoulou et al., 2015b; Varela-Ortega et al., 2016; Koopman et al., 2017; Rey et al., 2017; Crespo et al., 2019; Garnier and Holman, 2019)	2015; Papadaskalopoulou et al., 2015b; Varela-Ortega et al., 2016; Koopman et al., 2017; Crespo et al., 2019)	ou et al., 2015b; Varela-Ortega et al., 2016; Rey et al., 2017; Garnier and Holman, 2019)	Varela-Ortega et al., 2016; Koopman et al., 2017; Crespo et al., 2019)	al., 2016; Koopman et al., 2017; Crespo et al., 2019)	Papadaskalopoulou et al., 2015b)		
	Demand - Land management and cover change	(Papadaskalopoulou et al., 2015b; Carvalho-Santos et al., 2016; Varela-Ortega et al., 2016; Verkerk et al., 2017; Garnier and Holman, 2019; Papadimitriou et al., 2019)	(Papadaskalopoulou et al., 2015b; Carvalho-Santos et al., 2016; Varela-Ortega et al., 2016; Papadimitriou et al., 2019)	(Carvalho-Santos et al., 2016; Varela-Ortega et al., 2016)	(Carvalho-Santos et al., 2016; Varela-Ortega et al., 2016; Verkerk et al., 2017)	(Varela-Ortega et al., 2016; Verkerk et al., 2017)	(Garnier and Holman, 2019)	(Carvalho-Santos et al., 2016; Varela-Ortega et al., 2016; Verkerk et al., 2017; Papadimitriou et al., 2019)	(Carvalho-Santos et al., 2016; Varela-Ortega et al., 2016; Verkerk et al., 2017; Garnier and Holman, 2019; Papadimitriou et al., 2019)
	Monitoring and operational management, DEWS	(Papadaskalopoulou et al., 2015b; Verkerk et al., 2017; Garnier and Holman, 2019)	(Papadaskalopoulou et al., 2015b)	(Papadaskalopoulou et al., 2015b; Verkerk et al., 2017; Garnier and Holman, 2019)	(Papadaskalopoulou et al., 2015b)	(Papadaskalopoulou et al., 2015b; Verkerk et al., 2017)	(Verkerk et al., 2017)	(Verkerk et al., 2017)	

SM13.2 Supplementary Material Supporting Section 13.3

Table SM13.2: Literature sources used for assessment of major impacts on and risks for terrestrial and freshwater ecosystems in Europe for 1.5ºC and 3ºC GWL (Figure 13.8)

Terrestrial and freshwater ecosystems	Supporting references of assessment
Reduction in habitat availability of cold-adapted groups	(Balint et al., 2011; Dornelas et al., 2014; Hubble, 2014; Kovats et al., 2014; Oliver et al., 2014; McGill et al., 2015; Oliver et al., 2015; Saltré et al., 2015; Talavera et al., 2015; Barredo et al., 2016; Coll et al., 2016; Hellmann et al., 2016; Jørgensen et al., 2016; Liverpool, 2016; Dapporto et al., 2017; EEA, 2017b; Vermaat et al., 2017; Ciscar et al., 2018; Hillebrand et al., 2018; Sirois-Delisle and Kerr, 2018; Suggitt et al., 2018; Warren et al., 2018; Habel et al., 2019; Hinojosa et al., 2019; van Strien et al., 2019; Dullinger et al., 2020; Outhwaite et al., 2020; Soroye et al., 2020; Xi, 2020; Carnicer et al., 2021; Hodd et al., (2014).)
Reduction in biodiversity of cold-adapted groups	(Balint et al., 2011; Stefanescu et al., 2011; Dornelas et al., 2014; Oliver et al., 2014; Zografou et al., 2014; Hill and Preston, 2015; McGill et al., 2015; Oliver et al., 2015; Talavera et al., 2015; Hellmann et al., 2016; Hendriks, 2016; Jørgensen et al., 2016; Rizzetto et al., 2016; Stephens et al., 2016; Vodă et al., 2016; Dapporto et al., 2017; EEA, 2017b; Vermaat et al., 2017; Dyderski et al., 2018; Hillebrand et al., 2018; Sirois-Delisle and Kerr, 2018; Spooner et al., 2018; Suggitt et al., 2018; Warren et al., 2018; Dennis et al., 2019; Habel et al., 2019; Herrando et al., 2019; Hinojosa et al., 2019; van Strien et al., 2019; Dullinger et al., 2020; Kougioumoutzis et al., 2020; Outhwaite et al., 2020; Soroye et al., 2020; Xi, 2020)
Range shifts	(Parmesan et al., 1999; Wilson et al., 2007; Devictor et al., 2008; Lenoir et al., 2008; Jiguet et al., 2010; Chen et al., 2011; Scherrer and Körner, 2011; Devictor et al., 2012; De Frenne et al., 2013; Lenoir et al., 2013; Kovats et al., 2014; Bowler et al., 2015; Ancillotto et al., 2016; Jørgensen et al., 2016; Stephens et al., 2016; Wiens, 2016; Bowler et al., 2017; EEA, 2017b; Massimino et al., 2017; Mills et al., 2017; Pearce-Higgins et al., 2017; Sáenz-Romero et al., 2017; Bowler et al., 2018; Dyderski et al., 2018; Mori et al., 2018; Rumpf et al., 2018; Sirois-Delisle and Kerr, 2018; Spooner et al., 2018; Steinbauer et al., 2018; Suggitt et al., 2018; Bowler et al., 2019; Carnicer et al., 2019b; Gómez, 2019; Jaime et al., 2019; Lehikoinen et al., 2019a; Pérez Navarro et al., 2019; Post et al., 2019; Termaat et al., 2019; Vilà-Cabrera et al., 2019; Margalef-Marrase et al., 2020; Pavón-Jordán et al., 2020; Soroye et al., 2020; van Klink et al., 2020a; Zellweger et al., 2020; Urvois et al., 2021)
Changes in phenology	(Ovaskainen et al., 2013; Thackeray et al., 2013; Frolov et al., 2014a; Garonna et al., 2014; Karlsson, 2014; Plard et al., 2014; Schröder et al., 2014; van Vliet et al., 2014; Fu et al., 2015; Gill et al., 2015; Malcolm et al., 2015; Roberts et al., 2015; Gaüzère et al., 2016; Newson et al., 2016; Szabó et al., 2016; Thackeray et al., 2016a; EEA, 2017b; Gauzere et al., 2017; Glushenkov, 2017; Güsewell et al., 2017; Halupka and Halupka, 2017; Mayor et al., 2017; Miles et al., 2017; Prokosheva, 2017; Wang et al., 2017a; Asse et al., 2018; Chen et al., 2018; Chizhikova, 2018; Cohen et al., 2018b; Donnelly et al., 2018; Hidalgo-Galvez et al., 2018; Posledovich et al., 2018; Vitasse et al., 2018; Wu et al., 2018; Bobretsov et al., 2019; Fraga et al., 2019; Jakoby et al., 2019b; Lehikoinen et al., 2019a; Ma et al., 2019; Macgregor et al., 2019; Peaucelle et al., 2019; Piao et al., 2019; Prislan et al., 2019; Tishkov et al., 2019; Delgado et al., 2020; Menzel et al., 2020; Orellana-Macías et al., 2020; Wang et al., 2020; Keogan et al., 2021; Rosbakh et al., 2021)

Decrease in ecosystem production	(Nabuurs et al., 2003; Ciais et al., 2005; Schröter et al., 2005; Smith et al., 2005; Reichstein et al., 2007; Schulze et al., 2009; Carnicer et al., 2011; Fantappié et al., 2011; Elmendorf et al., 2012; Carnicer et al., 2013; Coll et al., 2013; Peñuelas et al., 2013; Kovats et al., 2014; Ruiz-Benito et al., 2014; Schröter et al., 2014; Gazol et al., 2015b; Keenan et al., 2016; Naudts et al., 2016; Novick et al., 2016; Polce et al., 2016; Schubert et al., 2016; Tian et al., 2016; van der Plas et al., 2016; Yigini and Panagos, 2016; Ballantyne et al., 2017; Bright et al., 2017; EASAC, 2017; EEA, 2017b; Nabuurs et al., 2017; Peñuelas et al., 2017a; Peñuelas et al., 2017b; Ratcliffe et al., 2017; Schwalm et al., 2017; Teuling et al., 2017; Valade et al., 2017; Gazol et al., 2018; Humphrey et al., 2018; Lugato et al., 2018; Luyssaert et al., 2018; Nabuurs, 2018; Sanginés de Cárcer et al., 2018; Stocker et al., 2018; Torralba et al., 2018; Verhagen et al., 2018; Carnicer et al., 2019a; Ciais et al., 2019; EASAC, 2019; Fernández-Martínez et al., 2019; Green et al., 2019; Jaime et al., 2019; Lee et al., 2019; Natali et al., 2019; Pérez Navarro et al., 2019; Post et al., 2019; Stocker et al., 2019; Xu et al., 2019; Yuan et al., 2019; Zhou et al., 2019; Batllori et al., 2020; Brodribb et al., 2020; Ito et al., 2020; Krause et al., 2020; Lian et al., 2020; Margalef-Marrase et al., 2020; Schuldt et al., 2020; Wang 2020; Zhang et al., 2020; Canadell and Jackson, 2021; Roces-Díaz et al., 2021; Yu et al., 2021)
Rising incidence of fire	(Moriondo et al., 2006; Bondur, 2011; Dury et al., 2011; Bedia et al., 2014; Turco et al., 2014; Drobyshev et al., 2015; Jolly et al., 2015; Tedim et al., 2015; Wu et al., 2015b; Drobyshev et al., 2016; Khabarov et al., 2016; Regos et al., 2016; Turco et al., 2016; Camia, 2017; de Rigo et al., 2017b; Forzieri et al., 2017; Fréjaville, 2017; Ruffault et al., 2017; Sitnov et al., 2017; Turco et al., 2017; Bedia et al., 2018; Filipchuk et al., 2018; Lahaye et al., 2018; San-Miguel-Ayanz et al., 2018; Sitnov and Mokhov, 2018; Turco et al., 2018a; Turco et al., 2018b; Chergui, 2019; Michetti and Pinar, 2019; Nolde, 2019; Pausas, 2019; Costa, 2020; Di Giuseppe et al., 2020; Dupuy et al., 2020; Royé et al., 2020)
Reduced pollination services (Reduction of regulating ecosystem services)	(Menéndez et al., 2006; Roberts et al., 2011; Franzén and Öckinger, 2012; Carvalheiro et al., 2013; Polce et al., 2014; Kaloveloni et al., 2015; Kerr et al., 2015; Rasmont et al., 2015; Tzilivakis et al., 2015; Ipbes, 2016; Petz et al., 2016; Settele et al., 2016; Radenković et al., 2017; Marshall et al., 2018; Fourcade et al., 2019; Powney et al., 2019; Steele et al., 2019; Van Dooren, 2019; Soroye et al., 2020; Zattara and Aizen, 2020; Vasiliev and Greenwood, 2021)
Increased soil erosion. (Reduction of regulating ecosystem services)	(Bangash et al., 2013; Mezösi et al., 2013; Routschek et al., 2014; Anaya-Romero et al., 2015; Cilek et al., 2015; European Commission, 2015; Panagos et al., 2015; Serpa et al., 2015; Sobol et al., 2015; Tzilivakis et al., 2015; Adler-Nissen, 2016; Borrelli et al., 2016; Grossel et al., 2016; Guerra et al., 2016; Polce et al., 2016; Li et al., 2017; Litvin et al., 2017; Panagos et al., 2017; Prins et al., 2017; Chizhikova, 2018; Gusarov et al., 2018; Auerswald and Fiener, 2019; Mullan et al., 2019; Pastor et al., 2019a; Berberoglu et al., 2020; Borrelli et al., 2020; Ciampalini et al., 2020; Gianinetto et al., 2020; Gusarov, 2020; Luetzenburg et al., 2020; Morán-Ordóñez et al., 2020; Rodrigues et al., 2020; Svetlitchnyi, 2020)

Table SM13.3: Percentage of species per group remaining within their suitable climate conditions (Warren et al., 2018) supporting Figure 13.9.

Species projected to remain within their suitable climate conditions at increasing levels of climate change averaged over 21 CMIP5 climate models with standard deviation (std) (Warren et al., 2018). Increased loss of climatic niche from of 1.5 and 4.5 °C GWL. Risks appear to be lower on some groups though droughts, habitat fragmentation and loss are not considered and will exacerbate the risks while dispersal may reduce risk.

Plants										
Regions	1.5C GWL	Std	2C GWL	Std	2.7C GWL	Std	3.2C GWL	Std	4.5C GWL	Std

WCE	0.77	0.08	0.70	0.09	0.58	0.10	0.53	0.10	0.39	0.10
NEU	0.85	0.18	0.81	0.19	0.76	0.20	0.74	0.21	0.67	0.23
SEU	0.75	0.09	0.67	0.11	0.53	0.12	0.47	0.12	0.31	0.12
EEU	0.75	0.12	0.69	0.13	0.58	0.14	0.52	0.15	0.35	0.14
Insects										
Regions	1.5C GWL	Std	2C GWL	Std	2.7C GWL	Std	3.2C GWL	Std	4.5C GWL	Std
WCE	0.59	0.11	0.49	0.11	0.34	0.11	0.29	0.10	0.17	0.08
NEU	0.90	0.14	0.86	0.18	0.76	0.25	0.72	0.28	0.58	0.34
SEU	0.65	0.13	0.56	0.15	0.43	0.17	0.38	0.17	0.26	0.15
EEU	0.72	0.15	0.64	0.18	0.49	0.20	0.42	0.21	0.25	0.19
Pollinator										
Regions	1.5C GWL	Std	2C GWL	Std	2.7C GWL	Std	3.2C GWL	Std	4.5C GWL	Std
WCE	0.59	0.14	0.50	0.15	0.39	0.15	0.35	0.14	0.26	0.11
NEU	0.84	0.18	0.78	0.23	0.65	0.29	0.59	0.31	0.43	0.33
SEU	0.75	0.13	0.69	0.14	0.57	0.16	0.52	0.16	0.38	0.15
EEU	0.69	0.21	0.60	0.23	0.43	0.25	0.36	0.24	0.19	0.19
Amphibians										
Regions	1.5C GWL	Std	2C GWL	Std	2.7C GWL	Std	3.2C GWL	Std	4.5C GWL	Std
WCE	0.88	0.12	0.84	0.14	0.76	0.17	0.72	0.17	0.59	0.18
NEU	0.89	0.24	0.91	0.16	0.87	0.19	0.84	0.21	0.76	0.25
SEU	0.84	0.16	0.79	0.18	0.68	0.21	0.63	0.22	0.50	0.22
EEU	0.83	0.29	0.86	0.20	0.78	0.24	0.75	0.25	0.63	0.30
Reptiles										
Regions	1.5C GWL	Std	2C GWL	Std	2.7C GWL	Std	3.2C GWL	Std	4.5C GWL	Std
WCE	0.89	0.09	0.86	0.10	0.80	0.11	0.77	0.11	0.67	0.13
NEU	0.90	0.18	0.87	0.19	0.82	0.22	0.79	0.23	0.71	0.25
SEU	0.89	0.10	0.85	0.12	0.76	0.15	0.72	0.15	0.58	0.15
EEU	0.87	0.27	0.84	0.28	0.79	0.30	0.78	0.31	0.68	0.33
Birds										
Regions	1.5C GWL	Std	2C GWL	Std	2.7C GWL	Std	3.2C GWL	Std	4.5C GWL	Std
WCE	0.88	0.04	0.85	0.05	0.79	0.06	0.76	0.07	0.66	0.11
NEU	0.93	0.13	0.92	0.12	0.90	0.12	0.88	0.13	0.83	0.16
SEU	0.87	0.06	0.82	0.08	0.73	0.10	0.69	0.11	0.54	0.12
EEU	0.86	0.14	0.84	0.15	0.79	0.16	0.77	0.16	0.69	0.18
Mammals										
Regions	1.5C GWL	Std	2C GWL	Std	2.7C GWL	Std	3.2C GWL	Std	4.5C GWL	Std
WCE	0.79	0.10	0.73	0.11	0.61	0.12	0.55	0.12	0.42	0.12
NEU	0.90	0.11	0.87	0.12	0.81	0.16	0.77	0.17	0.63	0.23
SEU	0.78	0.12	0.70	0.14	0.59	0.16	0.54	0.16	0.38	0.15
EEU	0.80	0.16	0.75	0.19	0.65	0.20	0.60	0.19	0.44	0.16

SM13.3 Supplementary Material Supporting Section 13.4

Table SM13.4: Literature sources used for assessment presented in Figure 13.11

Impact/Risk	Supporting references of assessment
Loss of habitat availability	(Coma et al., 2009; Garrabou et al., 2009; Huete-Stauffer et al., 2011; Munari, 2011; Kersting et al., 2013; Brodie et al., 2014; Frolov et al., 2014b; Rivetti et al., 2014; Altieri and Gedan, 2015; García Molinos et al., 2016; Spencer et al., 2016; Bakanev, 2017; Jessen et al., 2017; Orekhova, 2017; Berlinski and Popov, 2018; Buonomo et al., 2018; Jokinen et al., 2018; Reusch et al., 2018; Schuerch et al., 2018; van der Spek, 2018; Wang et al., 2018; Filatov et al., 2019; Garrabou et al., 2019; Saraiva et al., 2019; Spivak et al., 2019; D'Amen and Azzurro, 2020; Jiang et al., 2020; Pavlova, 2020; Sandø et al., 2020; Stepanyan, 2020)

Shifts in ranges (incl. invasions), composition (taxonomic, functional), phenologies	(Kortsch et al., 2015; Assis et al., 2017; Bakanev, 2017; Frainer et al., 2017; Kotenev et al., 2017; Rasmussen et al., 2017; Raybaud et al., 2017; Townhill et al., 2017; Vasilakopoulos et al., 2017; Benedetti et al., 2018; Gaudin et al., 2018; Jonsson et al., 2018; Kotta et al., 2018; Minicheva et al., 2018; Townhill et al., 2018; Benedetti et al., 2019; Berdnikov et al., 2019; Casado-Amezúa et al., 2019; Chefaoui et al., 2019; de la Hoz et al., 2019; Erauskin-Extramiana et al., 2019; Filatov et al., 2019; Hjerne et al., 2019; Kröncke et al., 2019; Krovnin et al., 2019; Moullec et al., 2019; Wasmund et al., 2019; Baudron et al., 2020; Bedford et al., 2020; Clark et al., 2020; Desmit et al., 2020; Maltby et al., 2020; Martynova et al., 2020; Nohe et al., 2020; Pavlova, 2020; Pecuchet et al., 2020; Pennino et al., 2020; Pyatinsky et al., 2020; Stepanyan, 2020; Uriarte et al., 2021)
Reduction in growth and reproductive success	(Bramanti et al., 2013; Maier et al., 2013; Gazeau et al., 2014; Hennige et al., 2015; Wall et al., 2015; Ragazzola et al., 2016; Stiasny et al., 2016; Durant and Hjermann, 2017; Smoliński and Mirny, 2017; Thomsen et al., 2017; Capuzzo et al., 2018; Lindegren et al., 2018; Queirós et al., 2018; Sswat et al., 2018a; Sswat et al., 2018b; Stiasny et al., 2018; Coll et al., 2019; Franz et al., 2019; Goldberg et al., 2019; Herrera et al., 2019; Hidalgo et al., 2019; Sguotti et al., 2019a; Stiasny et al., 2019; Tanner et al., 2019; Tsikliras et al., 2019; Verezemskaya et al., 2019; Vieira et al., 2019; Voss et al., 2019; Denechaud et al., 2020; Maynou et al., 2020; Mitchell et al., 2020; Tanner et al., 2020; Ikpewe et al., 2021; Polte et al., 2021)
Loss of biodiversity	(Berlinski and Popov, 2018; IPBES, 2018; Filatov et al., 2019; Pyatinsky et al., 2020; Stepanyan, 2020)
Decline in production	(Maugendre et al., 2014; Arrigo and van Dijken, 2015; Laufkotter et al., 2015; Holt et al., 2016; Børsheim, 2017; Orekhova, 2017; Capuzzo et al., 2018; Holt et al., 2018; Minicheva et al., 2018; Berdnikov et al., 2019; Bryndum-Buchholz et al., 2019; Carozza et al., 2019; Free et al., 2019; Kwiatkowski et al., 2019; Lotze et al., 2019b; Verezemskaya et al., 2019; Lewis et al., 2020; Pyatinsky et al., 2020)
Emergence of harmful algal blooms and pathogens	(Frolov et al., 2014a; Baker-Austin et al., 2017; Semenza et al., 2017; Minicheva et al., 2018; Riebesell et al., 2018; Roggatz et al., 2019)
Reduction in ecosystem services	(Roebeling et al., 2013; Brodie et al., 2014; Carstensen et al., 2014; Kjesbu et al., 2014; Maugendre et al., 2014; Serra et al., 2015; Krumhansl et al., 2016; De los Santos et al., 2017; Gao et al., 2018; van der Spek, 2018; Wang et al., 2018; Moullec et al., 2019; Sguotti et al., 2019b; Sheverdyaev, 2019; Baudron et al., 2020; Maltby et al., 2020)

SM13.4 Supplementary Material Supporting Section 13.5

Table SM13.5: Literature sources used in the assessment of feasibility and effectiveness of adaptation options for food systems in Europe in Figure 13.14

		Effectiveness	**Feasibility**					
Impact Type	**Adaptation Option**		*Economic*	*Technological*	*Institutional*	*Socio-cultural*	*Ecological*	*Geophysical*
Heat stress	Irrigation	(Dono et al., 2013; Schaap et al., 2013; Sutton et al., 2013; Bird et al., 2016; Diogo et al., 2017; Siebert et al., 2017; Webber et al., 2018; Feyen et al., 2020; Holzkämper, 2020; Santillán et al., 2020; Kebede et al., 2021)	(Dono et al., 2013; Schaap et al., 2013; Sutton et al., 2013; Bird et al., 2016; Costa et al., 2016; Diogo et al., 2017; Holzkämper, 2020; Kebede et al., 2021)	(Dono et al., 2013; Schaap et al., 2013; Sutton et al., 2013; Bird et al., 2016; Costa et al., 2016; Diogo et al., 2017; Siebert et al., 2017; Neset et al., 2019; Holzkämper, 2020; Santillán et al., 2020; Kebede et al., 2021)	(Schaap et al., 2013; Mandryk et al., 2015; Bird et al., 2016; Kebede et al., 2021)	(Schaap et al., 2013; Sutton et al., 2013; Mandryk et al., 2015; Costa et al., 2016; Neset et al., 2019; Kebede et al., 2021)	(Dono et al., 2013; Sutton et al., 2013; Bird et al., 2016; Costa et al., 2016; Siebert et al., 2017; Webber et al., 2018; Neset et al., 2019; Holzkämper, 2020; Santillán et al., 2020; Kebede et al., 2021)	(Dono et al., 2013; Webber et al., 2018; Neset et al., 2019; Kebede et al., 2021)
	Change of sowing/harvest date	(Schaap et al., 2013; Trnka et al., 2014; Donatelli et al., 2015; Gabaldon-Leal et al., 2015; Peltonen-Sainio et al., 2016; Diogo et al., 2017; Feyen et al., 2020; Holzkämper, 2020)	(Schaap et al., 2013; Trnka et al., 2014; Donatelli et al., 2015; Diogo et al., 2017; Grüneis et al., 2018)	(Trnka et al., 2014; Donatelli et al., 2015; Gabaldon-Leal et al., 2015; Feyen et al., 2020; Holzkämper, 2020)	-	(Schaap et al., 2013; Donatelli et al., 2015; Mandryk et al., 2015; Peltonen-Sainio et al., 2016; Diogo et al., 2017; Grüneis et al., 2018)	(Donatelli et al., 2015; Peltonen-Sainio et al., 2016; Holzkämper, 2020)	(Schaap et al., 2013; Diogo et al., 2017; Holzkämper, 2020)

	Change of cultivars	(Sutton et al., 2013; Trnka et al., 2014; Gabaldon-Leal et al., 2015; Costa et al., 2016; Peltonen-Sainio et al., 2016; Rial-Lovera et al., 2017; Webber et al., 2018; Santillán et al., 2020)	(Sutton et al., 2013; Trnka et al., 2014; Rial-Lovera et al., 2017; Grüneis et al., 2018; Holzkämper, 2020)	(Sutton et al., 2013; Trnka et al., 2014; Gabaldon-Leal et al., 2015; Costa et al., 2016; Rial-Lovera et al., 2017; Webber et al., 2018; Feyen et al., 2020; Holzkämper, 2020; Santillán et al., 2020)	-	(Sutton et al., 2013; Costa et al., 2016; Peltonen-Sainio et al., 2016; Grüneis et al., 2018)	(Sutton et al., 2013; Rial-Lovera et al., 2017; Holzkämper, 2020; Santillán et al., 2020)	(Rial-Lovera et al., 2017; Webber et al., 2018; Santillán et al., 2020)
	Livestock management	(Vitali et al., 2015; Cox et al., 2016; Schauberger et al., 2020)	(Vitali et al., 2015; Schauberger et al., 2020)	(Morignat et al., 2014; Vitali et al., 2015; Cox et al., 2016; Schauberger et al., 2020)	-	(Vitali et al., 2015; Cox et al., 2016)	(Morignat et al., 2014; Vitali et al., 2015; Cox et al., 2016)	-
Drought	Irrigation	(Dono et al., 2013; Schaap et al., 2013; Sutton et al., 2013; Bird et al., 2016; Diogo et al., 2017; Stańczuk-Gałwiaczek et al., 2018; Webber et al., 2018; Harmanny and Malek, 2019; Holzkämper, 2020; Santillán et al., 2020)	(Dono et al., 2013; Schaap et al., 2013; Sutton et al., 2013; Costa et al., 2016; Diogo et al., 2017; Harmanny and Malek, 2019; Holzkämper, 2020; Kebede et al., 2021)	(Dono et al., 2013; Schaap et al., 2013; Sutton et al., 2013; Mandryk et al., 2015; van Duinen et al., 2015; Bird et al., 2016; Costa et al., 2016; Diogo et al., 2017; Stańczuk-Gałwiaczek et al., 2018; Harmanny and Malek, 2019; Feyen et al., 2020; Holzkämper, 2020;	(Schaap et al., 2013; Mandryk et al., 2015; Bird et al., 2016; Grüneis et al., 2018; Kebede et al., 2021)	(Schaap et al., 2013; Sutton et al., 2013; Mandryk et al., 2015; van Duinen et al., 2015; Costa et al., 2016; Grüneis et al., 2018; Stańczuk-Gałwiaczek et al., 2018; Harmanny and Malek, 2019; Kebede et al., 2021)	(Dono et al., 2013; Sutton et al., 2013; Bird et al., 2016; Costa et al., 2016; Stańczuk-Gałwiaczek et al., 2018; Webber et al., 2018; Harmanny and Malek, 2019; Holzkämper, 2020; Santillán et al., 2020; Kebede et al., 2021)	(Dono et al., 2013; Diogo et al., 2017; Harmanny and Malek, 2019; Santillán et al., 2020; Kebede et al., 2021)

				Santillán et al., 2020; Kebede et al., 2021)				
	Change of sowing/harvest date	(Schaap et al., 2013; Trnka et al., 2014; Donatelli et al., 2015; Gabaldon-Leal et al., 2015; Peltonen-Sainio et al., 2016; Diogo et al., 2017; Parent et al., 2018; Lamichhane et al., 2019; Feyen et al., 2020; Holzkämper, 2020)	(Schaap et al., 2013; Trnka et al., 2014; Donatelli et al., 2015; Diogo et al., 2017; Grüneis et al., 2018; Lamichhane et al., 2019)	(Trnka et al., 2014; Donatelli et al., 2015; Gabaldon-Leal et al., 2015; Feyen et al., 2020; Holzkämper, 2020)	-	(Schaap et al., 2013; Donatelli et al., 2015; Mandryk et al., 2015; Peltonen-Sainio et al., 2016; Diogo et al., 2017; Grüneis et al., 2018)	(Donatelli et al., 2015; Peltonen-Sainio et al., 2016; Holzkämper, 2020)	(Schaap et al., 2013; Diogo et al., 2017; Holzkämper, 2020)
	Change of cultivars	(Sutton et al., 2013; Trnka et al., 2014; Gabaldon-Leal et al., 2015; Costa et al., 2016; Peltonen-Sainio et al., 2016; Rial-Lovera et al., 2017; Parent et al., 2018; Webber et al., 2018; Santillán et al., 2020)	(Sutton et al., 2013; Trnka et al., 2014; Rial-Lovera et al., 2017; Grüneis et al., 2018; Holzkämper, 2020)	(Sutton et al., 2013; Trnka et al., 2014; Gabaldon-Leal et al., 2015; Costa et al., 2016; Rial-Lovera et al., 2017; Webber et al., 2018; Feyen et al., 2020; Holzkämper, 2020; Santillán et al., 2020)	-	(Sutton et al., 2013; Costa et al., 2016; Peltonen-Sainio et al., 2016; Grüneis et al., 2018)	(Sutton et al., 2013; Rial-Lovera et al., 2017; Holzkämper, 2020; Santillán et al., 2020)	(Rial-Lovera et al., 2017; Webber et al., 2018; Santillán et al., 2020)
	Soil management	(Schönhart et al., 2014; Rial-Lovera et al., 2017; Hamidov et al., 2018; Wiréhn, 2018;	(Schönhart et al., 2014; Rial-Lovera et al., 2017; Hamidov et al., 2018; Wiréhn,	(Schönhart et al., 2014; Rial-Lovera et al., 2017; Hamidov et al., 2018; Wiréhn,	(Rial-Lovera et al., 2017; Wiréhn, 2018; Jørgensen et al., 2020)	(Rial-Lovera et al., 2017; Wiréhn, 2018)	(Rial-Lovera et al., 2017; Hamidov et al., 2018; Wiréhn, 2018)	(Rial-Lovera et al., 2017; Hamidov et al., 2018; Wiréhn, 2018)

		Jørgensen et al., 2020; Wiréhn et al., 2020)	2018; EEA, 2019b; Wiréhn et al., 2020)	2018; Wiréhn et al., 2020)				
Flooding	Change of sowing/harvest date	(Sutton et al., 2013; Rial-Lovera et al., 2017; Stańczuk-Gałwiaczek et al., 2018; Neset et al., 2019)	(Rial-Lovera et al., 2017; Neset et al., 2019; Kebede et al., 2021)	(Sutton et al., 2013; Papadaskalopoulou et al., 2016; Rial-Lovera et al., 2017; Stańczuk-Gałwiaczek et al., 2018; Neset et al., 2019)	-	-	(Sutton et al., 2013; Stańczuk-Gałwiaczek et al., 2018; Neset et al., 2019; Kebede et al., 2021)	(Sutton et al., 2013; Stańczuk-Gałwiaczek et al., 2018; Neset et al., 2019; Kebede et al., 2021)
Compound and extreme weather	Plant & livestock breeding	(Trnka et al., 2014; Macholdt and Honermeier, 2017; Rial-Lovera et al., 2017; Costa et al., 2019a; Senapati et al., 2019; Wreford and Topp, 2020)	(Trnka et al., 2014; Macholdt and Honermeier, 2017; Rial-Lovera et al., 2017; Costa et al., 2019a; Senapati et al., 2019; Wreford and Topp, 2020)	(Rial-Lovera et al., 2017; Costa et al., 2019a; Senapati et al., 2019; Wreford and Topp, 2020)	-	-	(Wiréhn, 2018; Costa et al., 2019a; Holzkämper, 2020; Wreford and Topp, 2020)	(Rial-Lovera et al., 2017; Wreford and Topp, 2020)
	Mixed use - agroecology & agroforestry	(Lüscher et al., 2014; Moraine et al., 2014; Himanen et al., 2016; Hernández-Morcillo et al., 2018)	(Lüscher et al., 2014; Moraine et al., 2014; Himanen et al., 2016; Rojas-Downing et al., 2017; Hernández-Morcillo et al., 2018)	(Moraine et al., 2014; Hernández-Morcillo et al., 2018)	(Moraine et al., 2014; Hernández-Morcillo et al., 2018)	(Moraine et al., 2014; Hernández-Morcillo et al., 2018)	(Moraine et al., 2014; Hernández-Morcillo et al., 2018; Öllerer et al., 2019; Oggioni et al., 2020)	(Prem et al., 2014; Fornara et al., 2019; Oggioni et al., 2020; Ford et al., 2021)

	Agricultural policy changes	(Papadaskalopoulou et al., 2016; Erjavec et al., 2017; McVittie et al., 2018; Muenzel and Martino, 2018; Faria and Morales, 2020)	(Buelow and Cradock-Henry, 2018; Grüneis et al., 2018; McVittie et al., 2018; Muenzel and Martino, 2018; Sneessens et al., 2019; Faria and Morales, 2020)	(Li et al., 2017; Wiréhn, 2018; EEA, 2019b; Szumelda, 2019)	(Reidsma et al., 2015; Papadaskalopoulou et al., 2016; Li et al., 2017; Grüneis et al., 2018; McVittie et al., 2018; Muenzel and Martino, 2018; Wiréhn, 2018; Sneessens et al., 2019; Szumelda, 2019; Faria and Morales, 2020; Jørgensen et al., 2020; Mitter et al., 2020)	(Li et al., 2017; Buelow and Cradock-Henry, 2018; Nguyen et al., 2019; Sneessens et al., 2019; Szumelda, 2019)	(McVittie et al., 2018; Muenzel and Martino, 2018; Faria and Morales, 2020)	(McVittie et al., 2018; Muenzel and Martino, 2018; Faria and Morales, 2020)
	Training & information	(Li et al., 2017; Rial-Lovera et al., 2017; Buelow and Cradock-Henry, 2018; Nguyen et al., 2019)	(Rial-Lovera et al., 2017; McVittie et al., 2018; Szumelda, 2019)	-	(Li et al., 2017; Rial-Lovera et al., 2017; McVittie et al., 2018)	(Nguyen et al., 2019; Szumelda, 2019)	(Li et al., 2017; Rial-Lovera et al., 2017; McVittie et al., 2018)	(Li et al., 2017; Rial-Lovera et al., 2017; McVittie et al., 2018)
	Crop selection changes	(Lüscher et al., 2014; Trnka et al., 2015; Rial-Lovera et al., 2017; Li et al., 2018; Harmanny and Malek, 2019)	(Lüscher et al., 2014; Reidsma et al., 2015; Wiréhn, 2018; Wiréhn et al., 2020)	(Lüscher et al., 2014; Trnka et al., 2015; Rial-Lovera et al., 2017; Li et al., 2018; Wiréhn et al., 2020)	-	(Himanen et al., 2016; Ricart et al., 2019)	(Rial-Lovera et al., 2017; Li et al., 2018; Harmanny and Malek, 2019; Wiréhn et al., 2020)	(Rial-Lovera et al., 2017; Li et al., 2018; Harmanny and Malek, 2019; Wiréhn et al., 2020)

	Land cover change, inc. agricultural land abandonment	(Leclère et al., 2013; Dunford et al., 2015; Kebede et al., 2021)	(Dunford et al., 2015; Alexander et al., 2018; Kebede et al., 2021)	(Leclère et al., 2013; Mandryk et al., 2015; Alexander et al., 2018)	(Mandryk et al., 2015)	(Leclère et al., 2013; Mandryk et al., 2015; Neset et al., 2019)	(Dunford et al., 2015; Rabin et al., 2020; Kebede et al., 2021)	(Dunford et al., 2015; Rabin et al., 2020; Kebede et al., 2021)
Disease pathogen & vectors	Plant & livestock breeding	(Hoffmann, 2013)	(Hoffmann, 2013)	(Hoffmann, 2013)	(Hoffmann, 2013; Grüneis et al., 2018)	(Hoffmann, 2013; Neset et al., 2019)	-	-
	Management, including high frequency rotations	(Maclachlan and Guthrie, 2010; Skuce et al., 2013; Moraine et al., 2014)	(Maclachlan and Guthrie, 2010; Morgan and van Dijk, 2012; Wiréhn et al., 2020)	(Dórea et al., 2016; Harrus & Baneth, 2005; Moraine et al., 2014; Pascual-Linaza et al., 2014; Skuce et al., 2013)	(Harrus and Baneth, 2005; Moraine et al., 2014; Roberts et al., 2014; Dórea et al., 2016)	(Morgan and van Dijk, 2012; Wiréhn et al., 2020)	(Acevedo et al., 2010; Maclachlan and Guthrie, 2010; Martínez-López et al., 2014; Moraine et al., 2014; Rose Vineer et al., 2020)	(Maclachlan and Guthrie, 2010; Moraine et al., 2014; Paz, 2015; Tjaden et al., 2018; Rose Vineer et al., 2020)
Combined impacts on productivity	International trade changes	(Dunford et al., 2015; Holman et al., 2016; Alexander et al., 2018; EEA, 2019b)		-	-	(Dunford et al., 2015; Holman et al., 2016; Mitter et al., 2020; Kebede et al., 2021)	(Dunford et al., 2015; Holman et al., 2016; Kebede et al., 2021)	(Alexander et al., 2018; EEA, 2019b)
	Consumer shifts in consumption	-	(Dunford et al., 2015; Mitter et al., 2020)	-	-	(Dunford et al., 2015; Mitter et al., 2020)	-	-

SM13.5 Supplementary Material Supporting Section 13.6

Table SM13.6: Sign of future change in onshore wind power potential under global warming levels (Figure 13.16)

Subregion	Area in study	Onshore wind power potential - Sign of change					
		1.5 °C		2 °C		≥ 3°C	
Northern Europe							
(Davy et al., 2018)	Europe, north Africa, Middle East	-		-	No model agreement over large areas	-	No model agreement over large areas
(Moemken et al., 2018)	Europe	-		+/-	+ only over a minor part of Scandinavia W: + in central Scandinavia, - in the rest. S: - except northern Norway	+/-	+ over northern Scandinavia W: + in almost all areas S: -
(Devis et al., 2018)	Europe	+	W: + S: + except – in the Baltic				
(Tobin et al., 2018a)	EU & Switz.	-	some ensemble members project increases up to +5%	-	some ensemble members project increases up to +4%	-	some ensemble members project increases up to +4%
(Reyers et al., 2016)	Europe (w.o. Russia)			+	W: +, S: -	+	W: +, S: -
(Carvalho et al., 2017b)	Europe (w.o. Russia)	-	- in south UK & northern Norway - rest not statistically significant W: few -, rest * S: few -, most Scandinavia *	+/-	+ in southern Finland, not statistically significant in southern Norway W: few -, rest * S: +/-, most Scandinavia *	+/-	+ in southern Finland, not statistically significant in southern Norway W: few -, rest * S: +/-, most Scandinavia *
(Tobin et al., 2016)	Europe	-		-			
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	EU	ct		ct		-	
Western Central Europe							
(Reyers et al., 2016)	Europe (w.o. Russia)			ct/+/-	ct over half of France, - in the rest of France	ct/+/-	ct over half of France, - in the rest of France
(Moemken et al., 2018)	Europe	-		-	W: +/- (and opposite signs of change between RCMs over large areas), S: +/-	+/-	+ over coastal Poland W: +/- (and opposite signs of change between RCMs over most areas), S: +/- (but – in most areas)
(Davy et al., 2018)	Europe, north Africa, Middle East	-	no model agreement over France, Belarus, Ukraine.	-	no model agreement over Poland, Belarus	+/-	no model agreement over large areas. Parts of Ukraine and Belarus with +.
(Carvalho et al., 2017b)	Europe (w.o. Russia)	-	not statistically significant changes over large areas	-	not statistically significant changes over large areas	-	not statistically significant changes over large areas

Subregion	Area in study	Onshore wind power potential - Sign of change					
		1.5 ºC		2 ºC		≥ 3ºC	
			W: -, S: -		W: -, S: -		W: -, S: -
(Devis et al., 2018)	Europe	+/-	- in Belarus, Ukraine and most of France W: +/-, S: +/-				
(Tobin et al., 2018a)	EU & Switz.	-		-		-	
(Tobin et al., 2016)	Europe	+/-	- for Poland	+			
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	EU	ct		ct		+	
Southern Europe							
(Solaun and Cerdá, 2020)	Spain	+/-		+/-			
(Katopodis et al., 2019)	Greece	+/-		+/-			
(Reyers et al., 2016)	Europe			+/-	+ only over few areas in Turkey and Greece. High robustness in – sign. W: -, S: +/-	-	High robustness in sign W: -, S: +/-
(Moemken et al., 2018)	Europe	+/-	+ in Turkey, large part of Italy and Greece, and southern France	+/-	+ in Turkey W: - except southern France and central Italy S: + in Turkey and most Spain, - in the rest	+/-	+ in coastal Turkey W: - except Croatia, central Italy and southern France where models disagree S: +/-
(Davy et al., 2018)	Europe, north Africa, Middle East	+/-	+ over coastal Turkey and a few more locations	+/-	+ over coastal Turkey and a few more locations	+/-	+ over a small part of coastal Turkey
(Devis et al., 2018)	Europe	-	W: -, S: + in south Iberia, in the rest – in the day and + in the night				
(Carvalho et al., 2017b)	Europe	-	in Turkey, changes * W: few -, rest *, S: +/-, most *	-	in Turkey, changes * W: few -, rest *, S: +/-, most *	+/-	+ over northern Turkey W: -, Turkey mostly * S: +/- (+ in Turkey and north Iberia)
(Tobin et al., 2018a)	EU & Switz.	+/-	+ only for Greece	+/-	+ only for Greece	+/-	+ only for Greece
(Tobin et al., 2016)	Europe	-		-			
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	EU	ct		ct		+	
Eastern Europe							
(Devis et al., 2018)		+	W: +, S: +/-				
(Carvalho et al., 2017b)		-	W: -, S: -	-	W: -, S: -	-	W: -, S: -

Subregion	Area in study	Onshore wind power potential - Sign of change		
		1.5 ºC	2 ºC	≥ 3ºC
(Davy et al., 2018)	Europe, north Africa, Middle East	-	- No model agreement over a large part of the subregion	- no model agreement over most of the subregion
(Moemken et al., 2018)		-	- W: - over south-western Russia, disagreement between RCMs on north-western Russia, S: -	- W: - no model agreement between RCMs on sign, S: -

Table Notes:

a) +: increase, -: decrease, +/-: + in some regions and – in others, ct: no change, W: winter, S: summer, *: not statistically significant. b) For those studies not reporting a global warming level but only an RCP scenario-timeline combination, the latter was associated with the relevant global mean temperature increase.

Table SM13.7: Magnitude of future change in onshore wind power potential under global warming levels (Figure 13.16)

Subregion	Onshore wind power potential – Magnitude of change			Measurement unit in study
	1.5ºC	2ºC	≥ 3ºC	
Northern Europe				
(Davy et al., 2018)	-3% to 0%	-8% to 0%	-10% to 0%	wind power density
(Moemken et al., 2018)	-2% to 0%	-8% to +4% *(W: -6% to +6%, S: -12% to +6%)*	-8% to +6% *(W: -4% to +14%, S: -20% to -4%)*	wind energy output
(Devis et al., 2018)	+4% to +8% *(W: up to +7%, S: -7% to +6%)*			mean power output
(Tobin et al., 2018a)	-2% to 0%	-2% to -1%	-6% to -2.5%	wind power production
(Reyers et al., 2016)		0% to +1% *(W: 0% to +3%, S: -3% to +0%)*	+1% to +4% *(W: 0% to +8%, S: -7% to 0%)*	wind energy output
(Carvalho et al., 2017b)	-15% to 0% *(W: -15% to -5%, S: -15% to -5%)*	-20% to +20% *(W: -15% to -5%, S: -15% to +20%)*	-20% to +30% *(W: -15% to 0%, S: -30% to +15%)*	wind energy density
(Tobin et al., 2016)	-2% - -1%	-3% - -1%		annual energy yield
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	0%	0%	-5% - -1%	electricity production from wind
Western Central Europe				
(Reyers et al., 2016)		-1% to +1%	-1% to +2%	wind energy output
(Moemken et al., 2018)	-2% to 0%	-4% to 0% *(W: -4% to +12%, S: -14% to +0%)*	-6% to +4% *(W: -4% to +18%, S: -18% to +4%)*	wind energy output
(Davy et al., 2018)	-3% to 0%	-3% to 0%	-5% to +2%	wind power density
(Carvalho et al., 2017b)	-30% to 0% *(W: -40% to -5%, S: -30% to -5%)*	-12% to 0% *(W: -40% to -5%, S: -30% to -5%)*	-12% to 0% *(W: -40% to -5%, S: -30% to -5%)*	wind energy density
(Devis et al., 2018)	-3% - +5% *(W: -5% to +5%, S: -8% to -5%)*			mean power output

	Onshore wind power potential – Magnitude of change			
Subregion	1.5°C	2°C	≥ 3°C	Measurement unit in study
(Tobin et al., 2018a)	-2.5% to 0%	-4% to -1%	-4% to -1%	wind power production
(Tobin et al., 2016)	-0.5% to +1%	-3% - +2%		annual energy yield
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	0%	0%	0% - +2%	electricity production from wind
Southern Europe				
(Solaun and Cerdá, 2020)	-8.2%- +5%	-8%- +6.5%		production
(Katopodis et al., 2019)	-15% - +8%	-5% - +8%		wind potential
(Reyers et al., 2016)		-2% - +0.8% *(W: -2% to +0%, S: -6% to +1%)*	-4% - 0% *(W: -7% to -2%, S: -8% to +2%)*	wind energy output
(Moemken et al., 2018)	-4%- +4%	-6% - +4% *(W: -6% to +4%, S: -8% to +16%)*	-14% - +12% *(W: -16% to +16%, S: -12% to +18%)*	wind energy output
(Davy et al., 2018)	-5%- +7%	-8% - +6%	-17% - +15%	wind power density
(Devis et al., 2018)	-12% - -2% *(W: -12% to -6%, S: -8% to +6%)*			mean power output
(Carvalho et al., 2017b)	-10%- -5% *(W: -15% to -5%, S: -10% to -5%)*	-10% - -5% *(W: -15% to -5%, S: -20% to +20%)*	-15% - +5% *(W: -15% to -5%, S: -30% to +30%)*	wind energy density
(Tobin et al., 2018a)	-4% to +1%	-4% to +1%	-8% to +3%	wind power production
(Tobin et al., 2016)	-2% to -1%	-6% to -4%		annual energy yield
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	0%	0%	0% to +2%	electricity production from wind
Eastern Europe				
(Devis et al., 2018)	-10% to 0% *(W: -8% to +2%, S: -10% to +2%)*			mean power output
(Carvalho et al., 2017b)	-30% to -5% *(W: -20% to -10%, S: -30% to -5%)*	-10% to 0% *(W: -20% to -5%, S: -10% to -5%)*	-20% to -5% *(W: -20% to -5%, S: -20% to -5%)*	wind energy density
(Davy et al., 2018)	-5% to -3%	-8% to -3%	-15% to -5%	wind power density
(Moemken et al., 2018)	-2% to 0%	-2% to 0% *(W: -4% to +6%, S: -6% to +0%)*	-4% to 0% *(W: -4% to +8%, S: -12% to -4%)*	wind energy output

Table Notes:

In many studies, changes are provided in map format and thus figures in this table are our own interpretation of these map-based findings. Ranges illustrate variations within subregions. Values correspond to ensemble means, unless characterized otherwise.

Table SM13.8: Sign of future change in offshore wind power potential under global warming levels (Figure 13.16)

Subregion	Area in study	Offshore wind power potential - Sign of change					
		1.5 ºC		2 ºC		≥ 3ºC	
Northern Europe							
(Davy et al., 2018)	Europe, north Africa, Middle East	+/-	+ few parts of Baltic Sea, - in upper North Sea	+/-	+ most of Baltic Sea, - in lower North Sea	+/-	+ in Baltic Sea, - North Sea
(Moemken et al., 2018)	Europe	+/-	+ Baltic Sea, +/- in North Sea	+/-	+ Baltic Sea, - in North Sea W: + S: + Baltic Sea, - North Sea	+/-	+ Baltic Sea, - in North Sea W: +/- S: + Baltic Sea, - North Sea
(Reyers et al., 2016)	Europe			+/-	+/ Baltic Sea, +/- in the rest W: +, S: -	+/-	+/ Baltic Sea, +/- in the rest W: +, S: -
(Devis et al., 2018)	Europe	+	W: +, S: +				
Southern Europe							
(Katopodis et al., 2019)	Greece	+/-	- in Ionian Sea and most of the Aegean Sea	+/-	- in the Ionian Sea and most of the Aegean Sea		
(Reyers et al., 2016)	Europe			+/-	+/- Aegean Sea, - in the rest W: S:	-	- in almost all Aegean Sea and in the rest W: S:
(Koletsis et al., 2016)	Mediterranean & Black Sea	+/-	+ in the Aegean Sea, - in the rest			+/-	+ in the Aegean Sea, - in the rest
(Moemken et al., 2018)	Europe	+/-	+ in Aegean and Adriatic Seas, - in the rest	+/-	+ in Aegean and Adriatic Seas, - in the rest W: +/- S: + Aegean and Adriatic, - in the rest	+/-	+ in most of the Aegean Sea, - in the rest W: - S: + Aegean and Adriatic, - in the rest
(Devis et al., 2018)	Europe	-	- in most Mediterranean, ct in Aegean Sea W: - S: + in most Aegean Sea, +/- in the rest				
(Davy et al., 2018)	Europe, north Africa, Middle East	+/-	+ most Aegean Sea, - in the rest	+/-	+ most Aegean Sea, - in the rest	+/-	+ most Aegean Sea, - in the rest
(Alvarez and Lorenzo, 2019)	EU	+/-	+ most Aegean Sea, +/- in the rest	+/-	+ most Aegean Sea, - in most of the rest		

Table SM13.9: Magnitude of future change in offshore wind power potential under global warming levels (Figure 13.16)

Subregion	Offshore wind power potential – Magnitude of change			Measurement unit in study
	1.5ºC	2ºC	≥ 3ºC	
Northern Europe				
(Davy et al., 2018)	-3% to +3%	-1% to +5%	-10% to +7%	wind power density
(Moemken et al., 2018)	-2% to +4%	-2% to +4% *(W: -2% to +4%, S: -4% to +8%)*	-4% to +4% *(W: -4% to +4%, S: -8% to +6%)*	wind energy output
(Reyers et al., 2016)		-1% to +0.5% *(W: 0% to +2%, S: -2% to 0%)*	-1% to +1% *(W: 0% to +2%, S: -2% to 0%)*	wind energy output

Subregion	Offshore wind power potential – Magnitude of change 1.5°C	2°C	≥ 3°C	Measurement unit in study
(Devis et al., 2018)	0% to +3% *(W: 0% to +3%, S: 0% to +3%)*			mean power output
Southern Europe				
(Katopodis et al., 2019)	-15% to +5%	-15% to +5%		wind potential
(Reyers et al., 2016)		-1% to +1% *(W: 0% to +2%, S: -2% to 0%)*	-1% to +1% *(W: 0% to +2%, S: -2% to 0%)*	wind energy output
(Moemken et al., 2018)	-2% to +4%	-4% to +2% *(W: 0% to +4%, S: -4% to +8%)*	-8% to +4% *(W: -4% to +4%, S: -8% to +8%)*	wind energy output
(Koletsis et al., 2016)	> +5%		<-5% / > +5%	wind power
(Devis et al., 2018)	-4% to 0%			mean power output
(Davy et al., 2018)	-6% to +6%	-10% to +6%	-15% to +12%	wind power density

Table Notes:

In many studies, changes are provided in map format and thus figures in this table are our own interpretation of these map-based findings. Ranges illustrate variations within subregions. Values correspond to ensemble means, unless characterized otherwise.

Table SM13.10: Sign and magnitude of future change in solar power potential under global warming levels (Figure 13.16)

Subregion	Area in study	Solar power potential – Magnitude of change 1.5°C			2°C			≥ 3°C		
Northern Europe										
(Tobin et al., 2018a)	EU & Switz.	-		-4% to -1%	-		-6% to -2%	-		-8% to -3%
(Jerez et al., 2015)	Europe				-	higher decrease in northern Scandinavia	-10% to 0%	-	higher decrease in northern Scandinavia	-20% to 0%
(Gutiérrez et al., 2020)	Europe				+/-	- in southern Norway and north UK in one RCM	-5% to +20%			
					+/-	+ in southern UK and southern Sweden	-20% to +5%			
(Muller et al., 2019)	Europe	+/-	+ in south UK and Denmark	-3% to +2%	+/-	+ in south UK and Denmark	-6% to +2%			
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	EU	ct			ct					
Western Central Europe										
(Tobin et al., 2018a)	EU & Switz.	-		-3% to 0%	-		-3% to -1%	-		-4% to -1%

Subregion	Area in study	Solar power potential – Magnitude of change								
		1.5°C			2°C			≥ 3°C		
(Jerez et al., 2015)	Europe				-	negligible changes over France	-10% to 0%	-	uncertain changes over west France	-10% to 0%
(Gutiérrez et al., 2020)	Europe				+	2 RCMs (incl. aerosols). In RACMOE22, increases up to +15%	+5% to +30%			
					+/-	4 RCMs. + over France	-15% to +5%			
(Muller et al., 2019)	Europe	+		+1% to +2.5%	+		0% to +3%			
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	EU	ct			ct					
Southern Europe										
(Tobin et al., 2018a)	EU & Switz.	-		-1% to 0%	-		-1% to 0%	-		-1% to 0%
(Jerez et al., 2015)	Europe				-	uncertain changes over most of the Iberian Peninsula	-5% to 0%	-	negligible changes over most of the Iberian Peninsula	-5% to 0%
(Gutiérrez et al., 2020)	Europe				+	2 RCMs (incl. aerosols)	+5% to +25%			
					+/-	4 RCMs. + over most of the area	-5% to +5%			
(Muller et al., 2019)	Europe	+		+0.5% to 2.5%	+		+1% to +3%			
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	EU	ct			ct					
Eastern Europe										
(Jerez et al., 2015)	Europe				-		-10% to -5%	-	higher decrease in north-western Russia	-15% to -5%
(Gutiérrez et al., 2020)	Europe				+	2 RCMs (incl. aerosols)	+5% to +20%			
					-	4 RCMs.	-15% to -5%			
(Muller et al., 2019)	Europe	-		-3% to 0%	-		-6% to -2%			
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	EU	ct			ct			ct		

Table Notes:

a) In many studies, changes are provided in map format and thus figures in this table are our own interpretation of these map-based findings. Ranges illustrate variations within subregions. Values correspond to ensemble means, unless characterized otherwise.

b) Magnitude of change – measurement unit: Tobin et al., 2018 – PV power production, Jerez et al., 2015 - PV potential production, Gutiérrez et al, 2020 – surface solar radiation (and hence PV potential production), Müller et al., 2019 – yearly PV production, Després and Adamovic, 2020 – electricity production from PV. d) the sign and magnitude presented in the 1st line for Gutiérrez et al, 2020 corresponds only to the range values for the two RCMs which include the effect of aerosols (i.e., ALADIN53 and RACMO22E), while the results in the 2nd line corresponds to the range values for the rest four RCMs explored in this study.

Table SM13.11: Sign and magnitude of future change in hydropower potential under global warming levels (Figure 13.16)

Subregion	Area in study	Hydropower potential – Magnitude of change								
		1.5ºC			2ºC			≥ 3ºC		
Northern Europe										
(Tobin et al., 2018a)	EU & Switz.	+	lowest in UK & Ireland	+3% to +17%	+	lowest in UK & Ireland	+3% to +15%	+	lowest in & Ireland - some models predict >+30%.	+5% to +21%
(van Vliet et al., 2016a)	Global (incl. Europe)				+/-	+5-20% in northern Scandinavia, ±5% in most of the rest	-20% to +20%	+/-	+5-20% in most Norway, Sweden, northern Finland, and north UK. -20% to -5% in very few areas	-20% to +20%
(van Vliet et al., 2016c)	Global (incl. Europe)				+/-	High increase in northern Scandinavia	-10% to >+15%			
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	EU	+		0% to +4%	+		+1% to +7%	+		+2% to 13%
Western Central Europe										
(Tobin et al., 2018a)	EU & Switz.	+		+3% to +9%	+/-	- only in France. Highest + in Czech Rep and Poland.	-1% to +15%	+/-	- only in France. Highest + in Czech Rep and Poland.	-5% to +12%
(van Vliet et al., 2016a)	Global (incl. Europe)				+/-	-5% to +5% only in Germany. -40% to -20% in Bulgaria, Romania, and parts of Ukraine	-40% to +5%	+/-	-5% to +5% only in coastal Germany and Poland. -60% to -20% in most of the areas.	-60% to +5%
(van Vliet et al., 2016c)	Global (incl. Europe)				-		-15% to -5%			
(Anghileri et al., 2018)	Alps	-		-27%						
(Bombelli et al., 2019)	Italian Alps	+	-9.16% (CCSM4), +1.85% (EC-EARTH), +14.65% (ECHAM6) -> +2.5% (mean)		+	0.03% (CCSM4), +10.72% (EC-EARTH), +8.33% (ECHAM6) -> +6.4% (mean)		-	-6.3% (CCSM4), +0.23% (EC-EARTH), -7.23% (ECHAM6) -> -4.4% (mean)	
(Patro et al., 2018)	Italian Alps	+/-	+ when glacier area <10% of total basin area	-32% to +5%	+/-	+ when glacier area <10% of total basin area	-23% to +1%	+/-	+ when glacier area <10% of total basin area	-40% to +6%

Subregion	Area in study	Hydropower potential – Magnitude of change								
		1.5°C			2°C			≥ 3°C		
(Stucchi et al., 2019)	Italian Alps	-	-25% (CCSM4), -14% (EC-EARTH), -10% (ECHAM6) -> -16.3% (mean)		-	-28% (CCSM4), -10% (EC-EARTH), -13% (ECHAM6) -> -17% (mean)		-	-27% (CCSM4), -23% (EC-EARTH), -33% (ECHAM6) -> -28% (mean)	
(Adynkiewicz-Piragas and Miszuk, 2020)	Germany, Poland				-		-10% to 0%	-		-34% to -16%
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	EU	+		0% to +1% (median values)	+		+2% to +4% (median values)	+		+1% (median value)
Southern Europe										
(Tobin et al., 2018a)	EU & Switz.	+/-	+ only in Italy & Slovenia Decrease >10% in Greece, Spain and Portugal in some models.	-7% to +5%	+/-	+ only in Italy & Slovenia	-10% to +2%	+/-	+ only in Slovenia. Decrease >20% in Greece, Spain and Portugal in some models.	-18% to +2%
(van Vliet et al., 2016a)	Global (incl. Europe)				-	-20% to -5% only in Italy	-40% to -5%	-		-60% to -40%
(van Vliet et al., 2016c)	Global (incl. Europe)				-		<-15% to -10%			
(Lobanova et al., 2016)	Portugal (Tagus)	-		-50% to -10%	-		-50% to -10%	-		-60% to -40%
(Solaun and Cerdá, 2017)	Spain	-		-25% to -5%	-		-30% to -10%	-		-49% to -30%
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	EU	-		-1% (median value)	-		-3% (median value)	-		-2% (median value) - may reach -13% under extreme events
Eastern Europe										
(van Vliet et al., 2016a)	Global (incl. Europe)				+/-	>+5% in northern Russia, <-5% in western Russia	-20% to +20%	+/-	-5% to +5% in most of the areas	-20% to +20%
(van Vliet et al., 2016c)	Global (incl. Europe)				+/-	+ in northern Russia	-10% to +15%			
(Akentieva et al., 2014)	Russia	+/-		-8% to +14%	+/-		-10% to +18%			

Table Notes:

a) In many studies, changes are provided in map format and thus figures in this table are our own interpretation of these map-based findings. Ranges illustrate variations within subregions. Values correspond to ensemble means, unless characterized otherwise.

b) Magnitude of change – measurement unit: Tobin et al, 2018 – Hydropower production, van Vliet et al, 2016a – gross hydropower potential, van Vliet et al, 2016b - annual mean usable capacity of current hydropower plants, Després and Adamovic, 2020 – electricity production from existing hydropower plants, Anghileri et al., 2018 – electricity production, Bombelli et al., 2019 - yearly average energy production, Patro et al, 2018 – water volume used for energy production in hydropower plants, Stucchi et al, 2019 – energy production, Adynkiewicz-Piragas and Miszuk, 2020 – energy production, Després and Adamovic, 2020 – electricity production, Lobanova et al, 2016 – hydropower produced, Akentieva et al, 2014 - average annual electricity production.

Table SM13.12: Sign and magnitude of future change in bioenergy crops potential (rapeseed) under global warming levels (Figure 13.16)

Subregion	Area in study	Bioenergy potential – Magnitude of change				
		1.5ºC		2ºC	≥ 3ºC	
Western Central Europe						
(Jaime et al., 2018)	Global (incl Europe)	-	EU countries: -8.5% (CSIRO Mk2), -9% (Hadley CM3), -10.2% (MPI ECHAM4) -> -9.2% (mean)		-	EU countries: -7.6% (CSIRO Mk2), -22.2% (Hadley CM3), -24.9% (MPI ECHAM4) -> -18.2% (mean)
(Cronin et al., 2020)	Global (incl Europe)				+	+4% (no land restrictions both in past and future) +27% (SSP5, where urban, food agricultural land and protected areas excluded both in past and future), +1% (SSP5, but forest areas are not excluded both in past and future)
Eastern Europe						
(Jaime et al., 2018)	Global (incl Europe)	+	Rest of Europe (mainly Russia): +32.5% (CSIRO Mk2), +41.6% (Hadley CM3), +54.4% (MPI ECHAM4) -> +42.8% (mean)		+	Rest of Europe (mainly Russia): Russia: +15.8% (CSIRO Mk2), +44.2% (Hadley CM3), +58.8% (MPI ECHAM4) -> +39.6% (mean)
(Cronin et al., 2020)	Global (incl Europe)				+	(whole Russia): +210% (no land restrictions both in past and future), (whole Russia) +219% (SSP5, where urban, food agricultural land and protected areas excluded both in past and future), (whole Russia) +431% (SSP5, but forest areas are not excluded both in past and future)

Table Notes:

a) Magnitude of change – unit of measurement: Jaime et al, 2018 - % change of land suitable for rapeseed cultivation (to produce biofuels) compared to 1996, Cronin et al, 2020 - % change of total land that is moderately or highly suitable for energy crops cultivation (15 crops) compared to 1980-2009.

b) Jaime et al, 2018 presents results for EU countries as a total. According to the study, most of suitable land in the EU is and will remain in Western Central Europe and therefore the whole % change in the EU has been allocated to the Western Central Europe. It is noted that 'Eastern Europe' in the study correspond to 'Western Central Europe' in the present IPCC Assessment Report. c) The study also presents results for the whole suitable area for rapeseed cultivation and thus by subtracting the EU figures, the change in rest Europe and Western can be estimated. The figures for Eastern Europe in the table correspond to the total change in the rest Europe and Western Asia and thus are over-estimated.

c) Cronin et al, 2020 presents results for different subregions of Europe, which however do not match the definitions adopted in this IPCC chapter. Therefore, the reference's results -calculated from the data provided on the reference's supplementary material- for Russia are presented in Table 3.f under Eastern Europe, while EEU, FSU and WEU are presented as an aggregated figure under Western Central Europe.

Table SM13.13: Sign and magnitude of future change in thermoelectric power capacity under global warming levels (Figure 13.16)

Subregion	Area in study	Thermoelectric power capacity – Magnitude of change								
		1.5°C			2°C			≥ 3°C		
Northern Europe										
(Tobin et al., 2018a)	EU & Switz.	-		-7% το -2%	-		-10% το -3%	-		-15% το -7%
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	EU	-		-4% to 0%	-		-6% to 0%	-		-15% to 0%
(van Vliet et al., 2016c)	Global (incl. Europe)				-		<-15%			
(Byers et al., 2020)	UK				-	Cumulative impacts over 32 plants.	-18% (p5), -20% (p50), -45% (p95)	-	Cumulative impacts over 32 plants.	-36% (p5), -41% (p50), -58% (p95)
Western Central Europe										
(Tobin et al., 2018a)	EU & Switz.	-		-8% to -5%	-		-13% to -6%	-		-18% to -11%
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	EU	ct		0%	-		~0%	-	- for nuclear plants.	-2%
(van Vliet et al., 2016c)	Global (incl. Europe)				-		<-15%			
Southern Europe										
(Tobin et al., 2018a)	EU & Switz.	-		-7% to -1%	-	all countries except Portugal <-8%.	-12% to -1%	-	all countries except Portugal <-14%.	-18% to -1%
(Després and Adamovic, 2020) (Després and Adamovic, 2020)	EU	-	- for nuclear plants. Figure results from impacts on whole energy system.	-2% to 0%	-	- for nuclear plants. Figure results from impacts on whole energy system. -13% under extreme events.	-5% to -1% (and may reach -12% under extreme events)	-	- for nuclear plants. Figure results from impacts on whole energy system. -12% under extreme events.	-8% to -2% (and may reach -12% under extreme events)
(van Vliet et al., 2016c)	Global (incl. Europe)				-		<-15%			
(Payet-Burin et al., 2018)	Iberian Peninsula	-	a) Average for all freshwater-cooled plants: -18% to -6% (annual) W: -12% to -1%, S: -30% to -16%							
			b) Once-through cooling: -16% to -11% (annual), S: -40% to -31% Closed circuit cooling: <-0.5%							

Subregion	Area in study	Thermoelectric power capacity – Magnitude of change						
		1.5°C	2°C			≥ 3°C		
Eastern Europe								
(van Vliet et al., 2016c)	Global (incl. Europe)		-		-10% to -5%			
(Klimenko et al., 2018)	Russia		-	Efficiency reduction by 0.2-0.6% per +1°C	-1.2% to -0.4% *(if a +2°C is considered)*	-	Efficiency reduction by 0.2-0.6% per +1°C	up to -2% *(if a +3°C is considered)*

Table Notes:

a) In many studies, changes are provided in map format and thus figures in this table are our own interpretation of these map-based findings. Ranges illustrate variations within subregions. Values correspond to ensemble means, unless characterized otherwise.

b) Magnitude of change – measurement unit: Tobin et al, 2018 – thermoelectric power production, van Vliet et al, 2016b - annual mean usable capacity of thermoelectric power plants, Després and Adamovic, 2020 – electricity production from existing thermoelectric plants (incl. nuclear), Anghileri et al., 2018 – electricity production, Bombelli et al., 2019 - yearly average energy production, Patro et al, 2018 – water volume used for energy production in hydropower plants, Stucchi et al, 2019 – energy production, Adynkiewicz-Piragas and Miszuk, 2020 – energy production, Després and Adamovic, 2020 – electricity production, Lobanova et al, 2016 – hydropower produced, Akentieva et al, 2014 - average annual electricity production, Payet-Burin et al, 2018 – available power plant capacity of freshwater-cooled thermal power plants, Byers et al, 2020 – available power plant capacity at 99th percentile extreme day, Klimenko et al, 2018 – power plant efficiency.

Table SM13.14: Examples of adaptation options for reducing sectoral climate change risks (Figure 13.19)

Sector	**Risk and cause**	**Examples of adaptation options**	**Elements related to the implementation of adaptation options**
Thermoelectric power	Reduction/ Interruption of operation due to water cooling constraints	Replacement of once-through cooling by cooling towers - Dry air-cooling - Seawater cooling (for coastal plants) - Replacement by new better adapted plants (Behrens et al., 2017; EEA, 2019a; IAEA, 2019) (Gasbarro et al., 2016)	The choice of electricity producers between options is guided mainly by the economics of adaptation technologies, and less by the supply of information on future climate change (Bogmans et al., 2017). Costs for retrofitting cooling are site-specific and increase with the distance to water bodies, needs for additional structures and the plant's age (Sieber, 2013). Dry cooling for new plants is 3–4 times higher than wet recirculating system and 4–5.5 times higher than once-through cooling (IAEA, 2019), and could result in 10% efficiency losses (EEA, 2019a).
		Switching to alternative generation technologies with low water use, e.g. wind, solar PV (Porfiriev et al., 2017; EEA, 2019a) (Gasbarro et al., 2016)	Fragmentation of energy and water policy frameworks make cohesive energy and water management difficult (Byers et al., 2015; Behrens et al., 2017). Ignoring the impact of climate-induced water constraints may significantly increase the energy system costs (Khan et al., 2016).
		Inter-basin water transfer (Koch et al., 2014)	
		Use of 'non-traditional' water sources (e.g. recirculation of water from oil and gas fields or coal mines, treated wastewater from nearby cities, desalination, water reuse) (Sieber, 2013) (Gasbarro et al., 2016)	Near-by sources of 'non-traditional' waters may not exist or may be of insufficient capacity.
		Shift part of power production to estuaries or coasts (Byers et al., 2015)	Its implementation to high-demand areas could bring significant nationwide water reductions (Byers et al., 2015), provided that recipient plants can undertake the extra production.

Sector	Risk and cause	Examples of adaptation options	Elements related to the implementation of adaptation options
		Improved electricity interconnections (Behrens et al., 2017)	High investment costs.
		Demand management measures to reduce the economic losses during power curtailment (e.g., smart grid/meters, pricing options, energy efficiency (Gasbarro et al., 2016)	Can be an effective option, particularly under low climate change scenarios (Hanski et al., 2018).
		Institutional measures (e.g. water temperature cap, heat load plan, contract between environmental regulator and electricity producers).	The efficiency of institutional adaptation options may differ depending on the increase of heat waves intensity, frequency or both (Eisenack, 2016). Stakeholder engagement to prevent the conflicts with the local communities in case of water curtailments is helpful (e.g., increase awareness of decreasing water flows, cooperation) (Gasbarro et al., 2016)
Hydropower	Reduced production due to lower streamflow	Adjusted hydropower management (Gaudard et al., 2013; EEA, 2019a).	By optimizing the hydraulic head and the turbine schedule with respect to the prices could reduce power losses up to 35% (Gaudard et al., 2013).
	Increased risk of damage from flooding	Adjusted hydropower management (Aparicio, 2017; Ranzani et al., 2018)	Adaptive strategies in the management of reservoirs could reduce (but not avoid) revenue losses (Ranzani et al., 2018)
		Recalibration of spillways, e.g. through PKW, concrete or metal fuse gates	Recalibration systems have been implemented successfully in hydropower facilities in Europe and outside Europe (EEA, 2019a).
		Increase the capacity of existing hydropower plants (i.e. increase installed turbine capacity, increase reservoir storage)	This option has been implemented in some northern European hydropower plants (EEA, 2016a)
		Hydropower operational warning systems, monitoring of snowpack and river flows, forecast of high water flows	Hydropower forecasting faces key challenges related to integration of state-of-the-art weather services, data assimilation schemes, links between forecast quality and value, and enhancement of risk-based decision-making (Boucher and Ramos, 2018).
Electricity transmission and distribution	Power outages due to damages of transmission lines and power stations from extreme winds, storm surges, floods and very high temperatures	Construction of new substations and overhead lines (providing additional paths to transfer power in case of a transmission line failures) - Improve old overhead lines and substations (Fu et al., 2018) (Gasbarro et al., 2016).	Efficiency increases when construction of new lines and stations occurs to decentralized power systems, while improvement of existing lines and stations is less efficient (Fu et al., 2018). The contribution of substations' refurbishment in building flood resilience depends on the degree of protection of critical substations which may not necessarily be the most vulnerable to high water levels (Bollinger and Dijkema, 2016). The willingness-to-pay (WTP) to avoid power outage is higher for older people, females and urban residents; risk perceptions are greatly influenced by current regional temperatures; and under strong warming the WTP increases in summer and decreases in winter in all countries, particularly in the north (Cohen et al., 2018a). Experience with previous power cuts significantly enables resilience (Ghanem et al., 2016; Cohen et al., 2018a).
		Vegetation management	New technologies (e.g. Lidar) allow to reduce the need for time-consuming and labour-intensive traditional

Sector	Risk and cause	Examples of adaptation options	Elements related to the implementation of adaptation options
			verification and to provide reliable input for guiding tree trimming. Though, their implementation may require significant changes of management practices at utility level.
		Turn, partially or totally, overhead lines into underground cables (Wang et al., 2016; Ciasca et al., 2017).	High installation cost Potentially long implementation time, depending on the area covered and the length of cables (EEA, 2019a). Selective undergrounding of line sections exposed to higher risk or harder to access can be a cost-effective adaptation strategy (Wang et al., 2016). For new lines, potentially long permitting processes and public opposition (Wang et al., 2016; Ciasca et al., 2017).
		Locate assets above flood level, flood barriers, relocate assets (Bollinger and Dijkema, 2016; Wang et al., 2016; Thacker et al., 2018)	High investment costs for existing assets (Wang et al., 2016). Long implementation time (EEA, 2020c). TSOs often prefer to combine investments in flood defences with major renovations or refurbishments to substations, and consequently prioritization often occurs based on factors unrelated to a substation's criticality (e.g. on its age) (Bollinger and Dijkema, 2016; Wang et al., 2016). Assets' relocation is almost always not cost beneficial (Thacker et al., 2018).
		Distribution circuit segregation and automation (Wang et al., 2016).	
		Increase the height of poles supporting power lines, install conductors with hotter operating limits, use of 'low-sag' conductors (EEA, 2019a).	Legal requirements on minimum pole height support adaptation (EEA, 2019a).
	Reliability problems in electricity networks due to increased peak load for cooling	Strict efficiency standards for cooling equipment (EEA, 2019a; Palkowski et al., 2019).	Reliability can be increased through measures reducing cooling demand, such as improved building design, water cooling technologies for thermoelectric generation that do not use electricity (e.g. heat-driven absorption cooling), or direct utilisation of cooling water where available (EEA, 2019a).
		Increase transmission capacity, including international linkages	
		Increase backup capacity	
Transport	Reduction/ interruption of transportation due to damaged infrastructure and/or traffic disruption as a result of intense rain, flooding and heatwaves	Broad range of options (EEA, 2014; Frolov et al., 2014a; Burbidge, 2015; Stamos et al., 2015; van Slobbe et al., 2016; Bachner, 2017):	Particularly in road transport, measures have also economy-wide feedback effects which must be considered when assessing adaptation benefits (Bachner, 2017). Nevertheless, as it is difficult to quantify the benefits and costs of adaptation measures in transport, cost-benefit analyses need to be performed on a case study level (Doll et al., 2014).
		a) Infrastructure construction/retrofitting (e.g. enlargement of drainage systems, measures to reduce slippery roads, raise links above flood level)	As 'soft' adaptation options (e.g. ICT) have already been implemented to a large extent in railways, investments in advanced protection systems (e.g., tunnels, protection walls and enlarged drainage) are necessary to support proactive maintenance strategies (Doll et al., 2014). Improving drainage or elevate critical road links can be cost effective but requires analysis at city level (Pregnolato et al., 2017). Adaptations in vessel design may reduce the vulnerability to low depth, but with a trade-off with performance in times of sufficient discharge (van Slobbe et al., 2016).

Sector	Risk and cause	Examples of adaptation options	Elements related to the implementation of adaptation options
		b) Improved maintenance (e.g. vegetation management, visual road inspection)	Network maintenance can be a more cost-efficient way to reduce short- and medium-term damage risks (Doll et al., 2014).
		c) ICT and users (e.g. early warning on adverse weather, weather forecasting)	Lack of coherence between the climate adaptation plans of companies operating major transport infrastructure and their neighbouring municipalities may reduce the effectiveness of adaptation actions undertaken by the transport sector (EEA, 2014).
		d) Modal shifts	
		e) Technological innovations (e.g. heat-resistant pavement materials, materials designed for a greater number of cycles of freezing and thawing, logistic chains).	Some of the new pavement materials may increase noise levels in urban areas (Enríquez-de-Salamanca, 2019).
		f) Revising operational guidelines and standards	The location-specific nature of weather impacts requires analysis and response also at route level to ensure investments in flood protection are cost effective (EEA, 2020c). Dynamic heat management can reduce the heat-related disruption from unnecessary emergency speed restrictions (ESRs) on railway networks (Ferranti et al., 2016).
	Reduction of thermal comfort of passengers in railways and metro lines due to higher temperatures	Saloon cooling, cooling of platforms and tunnels (Jenkins et al., 2014a)	Saloon cooling alone may not be sufficient to maintain comfortable thermal conditions for some lines under high emission scenarios (Jenkins et al., 2014b).
Winter tourism	Reduction/Interruption of operation due to lack of snow	Snowmaking (including application of automated snowmaking systems)	High investment cost (i.e. for development of water supply systems, purchase and installation of snow cannons) and increased operational costs (Campos Rodrigues et al., 2018; Scott et al., 2019). Increased snowmaking can maintain snow reliability under low warming, but is not sufficient under high-end warming (Steiger and Scott, 2020). Snowmaking was found to reduce guest loyalty of skiing destinations in some customer segments by affecting the natural scenery and raising prices (Bausch et al., 2019)
		Protection and conservation of snowpack (e.g. water drainage, modification of the ski runs slopes, protection from avalanches, protection or storage of snow during the non-ski seasons). Snow farming (Steiger and Scott, 2020)	Several techniques are available.
		Expansion of skiable area	Need of substantial investments and free areas, has adverse impacts (e.g. land-use conflicts, impacts of construction on natural areas, impacts on the landscape quality, increased water and energy use) (Campos Rodrigues et al., 2018).
		Nocturnal skiing (Campos Rodrigues et al., 2018)	Nocturnal skiing already offered at some ski resorts, but it can compensate for a small part of potential

Sector	Risk and cause	Examples of adaptation options	Elements related to the implementation of adaptation options
			losses due to adverse weather and safety limitations (Campos Rodrigues et al., 2018).
		Shift to other ski destinations (spatial substitution)	The attachment ('loyalty') of glacier skiers to their favourite leisure destination, gender, demographics (i.e. age) and perceptions towards environmental sustainability were found to be important in guiding adaptation preferences (Demiroglu et al., 2018).
		Diversification of snow-based activities	Diversification may be too costly for some resorts. Skiing in indoor slopes may be the least preferred option for skiers, while other winter activities (e.g. snowboard, downhill skiing) may not be effective adaptation options as skiing is perceived as a necessity in some countries (Falk, 2015; Falk and Scaglione, 2018).
		Transformation to multi-recreational mountain resorts, compensating non-snow activities	Transformation can take place by diversifying the offer in winter towards nature-based activities or place-bound products beyond winter sports (Bausch and Gartner, 2020) and by developing year-round tourism and snow-independent tourism products (Steiger and Scott, 2020). Transformation may be too costly for some resorts (Campos Rodrigues et al., 2018). Non-snow activities not appealing to people for whom skiing is the main activity in their winter holiday (Steiger and Scott, 2020). Cultural differences affect the effectiveness of compensating activities (Landauer et al., 2013).
		Management options, e.g. grouping of resorts, pricing strategies (Campos Rodrigues et al., 2018)	Price discounts are effective under less severe warming scenarios (Steiger et al., 2020). Price discount in ski lift tickets may not be efficient for attracting foreign visitors (Falk and Scaglione, 2018).
Coastal and Summer tourism, Other forms of tourism	Loss of beaches/ coasts due to sea level rise and increased erosion	Hard defences (e.g. seawalls)	It is a measure that has been widely applied in Europe, but generally with no concern for future climate change impacts. It also requires high investments, proper maintenance (which is costly) and can affect sediment transport and coastal erosion (Pranzini et al., 2015).
		Soft measures(e.g. artificial beach nourishment, dune planting (Pranzini et al., 2015; Jiménez et al., 2017)	Selective sand nourishment is common in Europe (Pranzini et al., 2015), as in Spain where more than 22 mill m3 of sand were deposited on the Catalan coast during the last 30 years (Jiménez and Valdemoro, 2019). There is often a reduced availability and high costs of fill material. Potential governance difficulties (lack of well-defined roles in coordinating nearshore activities, division of costs between government, private owners and local communities).
		Inland shift of tourism activities	May not be possible due to land use and financial constraints, as well as environmental and administrative regulations.
	Disruption of tourism activities due to higher temperatures	Temporal shift/extension of recreational activities outside the summer period (e.g. transition time tourism, all year tourism)	Potential barriers include organizational issues, inability/reluctance of clientele (Mourey et al., 2020). Limiting factors to be considered include cost, school holidays or work (Brosy et al., 2014).

Sector	Risk and cause	Examples of adaptation options	Elements related to the implementation of adaptation options
	Disruption of tourism activities due to water scarcity	Water supply and demand measures (e.g. desalination; rainwater harvesting; water remediation and water reuse; water saving devices) (Michailidou et al., 2016)	Identification the suitable alternatives implies consideration of several and often conflicting criteria and stakeholder involvement (Michailidou et al., 2016)
Business	Reduction/ Interruption of operation due to extreme events; Asset damages; Reduced sales due to lower demand; Health and safety risks for staff.	Individual adaptation measures at enterprise and cluster level – general measures (e.g. risk assessment and monitoring, technical solutions, reduction of exposure through geographical decisions, shift and share risks, disaster relief and business continuity, portfolio diversification, and cooperation) (Pinkse and Gasbarro, 2019)	Potential barriers include lack of human/ financial resources and scientific/ technical knowledge to understand climate change risks (Aguinaldo et al., 2019); limited knowledge on scale of assessment, evidence base, adaptation response, scope of impacts, interdependencies, and public policy (Surminski et al., 2018). The cluster approach allows to overcome the lack of resources and knowledge to address climate risks and adaptation options, which characterize particularly small and medium size enterprises (Aguinaldo et al., 2019).
		Individual adaptation at enterprise and cluster level – Measures against heatwaves (e.g., shielding/ reflective surfaces; use of 'cool' materials; green walls; green parking and draining floors; energy management system; changes in working practices; appropriate clothing) (Ciscar et al., 2018; IRIS LIFE project, 2019)	Changes in working practices for outdoor workers: more frequent and longer breaks during the hottest parts of the day; earlier starts and/or later ends to the working day; night working. Other changes: provide drinking water; scheduling heavy work during the cooler parts of the day or reducing work during the hottest part of the day; alternate work and rest periods; wearing appropriate clothing; employees' education. Shifting the working hours from daytime to nighttime could entail side effects such as chronic fatigue, anxiety, depression, and noise pollution for nearby residents (Ciscar et al., 2018).
		Individual adaptation at enterprise and cluster levels – Measures against storms	Closing tunnel connection in case of strong wind; Tree pruning; Limited storage of materials outside the building; Shielding surfaces; Roof anchorage (IRIS_LIFE_project, 2019).
		Individual adaptation at enterprise and cluster levels – Measures against heavy rains/floods	Alert systems; Anti-reflux valves; Temporary meteoric water storage areas; Anti-flooding bulkheads; Storage of materials at a safe height from the ground (IRIS_LIFE_project, 2019).
		Individual adaptation at enterprise and cluster levels – Measures against drought	Drought causes reduced water availability for the processes within the factories. Potential measures include treatment and reuse of wastewater; sector-specific measures for reducing water consumption (Alkayal et al., 2015). In food and beverage: implementation of Best Available Techniques (BAT); sector-specific measures for meat and poultry, fish, fruit and vegetables, dairies and drink processing sectors (Valta et al., 2016).
		Corporate adaptation	Corporate strategies to climate risks still predominantly focus on mitigation (Sakhel, 2017; Pinkse and Gasbarro, 2019). It is dominated by surveillance of climatic changes, climate proofing production facilities and assets, and supply chain management (Sakhel, 2017).
Banking and finance	Risk of instability of the financial	Extension of financial regulations and requirements for risk monitoring towards climate-related	Only in a few European countries, such regulations are in place but are voluntary (D'Orazio and Popoyan, 2019)

Sector	Risk and cause	Examples of adaptation options	Elements related to the implementation of adaptation options
	system due to damages caused by climate extremes	risks, such as climate-related stress tests (TCFD, 2017; D'Orazio and Popoyan, 2019)	
Insurance	Risk of insurance default	Public reinsurance Extension of risk monitoring towards climate-related risks	
Cities	Reduced indoor and outdoor thermal comfort and power outages due to heatwaves [1]	Passive and active cooling measures in buildings (e.g. air-conditioning, ventilation, shading)	Coping appraisal is a strong predictor for citizens' motivation to adapt, while elderly are less motivated (Murtagh et al., 2019). Though necessary, natural ventilation alone cannot fully mitigate overheating (Dodoo and Gustavsson, 2016; Heracleous and Michael, 2018; Dino and Meral Akgül, 2019; Shen et al., 2020), and its effectiveness is strongly affected by occupants' behaviour (Tillson et al., 2013; van Hooff et al., 2014), while a combination of shading and ventilation (including night-time) is needed (Ibrahim and Pelsmakers, 2018). Installation of air-conditioning may be too costly for many households (Thomson et al., 2019). Large increase of air-conditioning in densely populated areas may exacerbate the urban heat island and thus overheating (Kingsborough et al., 2017), and increases pressures on electricity systems.
		Interventions at the buildings' shell, e.g. improving insulation, increasing thermal mass, use of phase-change materials (PCM)	Addition of insulation in poorly ventilated and shaded buildings may increase overheating. Altering the thermal mass is much harder in older buildings (Tillson et al., 2013). PCM could significantly reduce the cooling load, but is a relatively new technology to the construction industry, with many uncertainties (e.g. future prices, long-term durability, energy cost) (Sajjadian et al., 2015). Material changes to buildings are often prohibited by restrictive tenancy relations (Thomson et al., 2019).
		Green, blue, and grey infrastructure (e.g. green areas, green roofs/walls, cool roofs/facades, cool pavements)	Climatic conditions may affect performance of options (Ward et al., 2016). On-site water reuse systems can provide supplementary water to green roofs and walls, gardens, and other smaller-scale urban nature-based solutions on an as-needed basis. The cooling potential of plants in green roofs or walls is influenced by the choice of plant species (Cameron et al., 2014). Cool roofs are less expensive and easier to apply than green roofs (Carvalho et al., 2017a).People's willingness to pay for green infrastructure (GI) was found to be mostly related to income and ethnicity, while citizens are willing to support climate adaptation through GI as long as the GI is multifunctional, i.e., comes with recreational and aesthetic benefits. (Derkzen et al., 2017). Urban governance mechanisms and institutional barriers to GI planning need additional research (Emmanuel and Loconsole, 2015). Cool roofs are an established technology, but this is not yet the case for cool pavement materials which

Sector	Risk and cause	Examples of adaptation options	Elements related to the implementation of adaptation options
			may cause glare problems or excessive illuminance levels (Carnielo and Zinzi, 2013). Options are not easily transferable between countries or even cities (Hintz et al., 2018).
		Update building standards to consider the expected increase of extreme summer temperatures and the consequent increase of energy demand for cooling	Standards considering climate change and outdoor climate conditions, and realistic assumptions in terms of occupant adaptations are needed (Mulville and Stravoravdis, 2016; Sánchez-García et al., 2020; Shen et al., 2020). Standards should consider regional differences (Frolov et al., 2014a).
		Watering of roads and pavements	Emergency option during heat waves, but not a long-term adaptation option (Hendel et al., 2017; Enríquez-de-Salamanca, 2019). Optimization of possible watering methods has only rarely been conducted, while water consumption is an issue (Hendel et al., 2015).
		Escape to nearby mountainous regions (Juschten et al., 2019b)	Mostly motivated by social and subjective norms, past experience with heat stress, outdoor sports as a travel motive, previous visits to the destination, positive media coverage, and perceived behaviour control (Juschten et al., 2019a).
	Reduced water supply due to drought	Water demand management (Buurman et al., 2017)	Voluntary/ enforced water conservation. High degree of uncertainty regarding effectiveness, but when coupled with new water reuse infrastructure it could keep the probability of exceeding the target frequency of an emergency drought order below 0.01 in London under severe drought by 2100 for a medium emissions scenario and high population growth (Kingsborough et al., 2016).
		Expand water supply (Buurman et al., 2017)	Water reuse, new water reservoirs, inter-basin transfers, desalination, artificial aquifers. Less flexible as it requires commitment to supply infrastructure which can be maladaptive under increasing water demand (Kingsborough et al., 2016).
	Corrosion of buildings due to permafrost and thaw melting	Use of materials with proper resistance to freezing and thawing cycles (Frolov et al., 2014a) Increase corrosion resistance of structural elements (Frolov et al., 2014a)	Development of an assessment methodology and database on the durability of materials under various climatic conditions is needed to support the selection of optimal materials under the future climate. Regular updating of regulatory parameters based on observational data (Frolov et al., 2014a).
		Design solutions that prohibit an increase of moisture content in building structures (Frolov et al., 2014a)	
	Damage to settlements and infrastructure due to flooding	Building new flood defences (e.g. dikes)	Costs for maintaining the baseline flood protection level under climate change (and introducing a minimum of 100 years protection) through defences would not outweigh benefits for many countries before 2030 under different RCP/SSPs, while in 2080 adaptation benefits would exceed costs in almost all countries (Bouwer et al., 2018). Update and increased maintenance of storm barriers comes along with concerns on their environmental impacts as in St Petersburg (Rodionov, 2016).
		Heightening and/or strengthening of existing dikes, dams, and levees. Widening of river floodplains and reduction of obstructions in floodplains (Bouwer et al., 2018). Updating the urban drainage system (Bodoque et al., 2019).	

Sector	Risk and cause	Examples of adaptation options	Elements related to the implementation of adaptation options
			Decision making under deep uncertainty approaches can be applied to deal with uncertainties of climatic projections (Babovic et al., 2018). Information such as a high-resolution European and Mediterranean flash floods dataset can provide input to impact assessment, modelling and forecast (Amponsah et al., 2018).
		Flood protection measures at building/household level, such as dry-proofing (e.g. sealing walls with waterproof coatings, impermeable layering of masonry, sealants for openings), wet-proofing (e.g. building elevation, use of water-resistant materials), emergency measures (e.g. mobile flood barriers, sandbags), securement of sources of contamination	There is *high confidence* that past experience of damage strongly affects risk perception and hence motivation for adaptation (Baron and Petersen, 2015; Lujala et al., 2015; Osberghaus, 2015; Madsen et al., 2019). Though, protection may be motivated mostly by coping and threat appraisal and trust in public institutions (Bamberg et al., 2017). Dry-proofing is costly and thus usually applied to new buildings (Bouwer et al., 2018). The level of wet-proofing differs significantly between locations (Koerth et al., 2013; Stojanov et al., 2015). Perceptions of flood risks, expected climate impacts, risk attitudes and geographical characteristics were found to be the most important determinants in the decision to invest in elevating houses (Botzen et al., 2013).
		Nature-based solutions (NbS) to manage water runoff, e.g. multifunctional green spaces, wetlands, retention/detention and infiltration basins, rain gardens and green roofs	Natural ecosystems remain under threat from changing climatic conditions. Potential barriers for development of green infrastructure for flood risk management include coordination and convincing stakeholders, limitations of the existing legislations, and difficulty in accounting non-monetary benefits (Liu and Jensen, 2018).
		Facilitate recovery after climate extremes	The location and composition of urban green spaces is key for effective adaptation (García Sánchez et al., 2018)
		Increase flood risk standards, land use planning, risk zoning, dedicated flood management legislation	Measures that work well in one region may not be effective in another region facing different flood hazards, and thus building codes and rest flood risk management policies have to be region-specific (Poussin et al., 2015). Legislation to delimit non-suitable land for urbanization often shows a slow implementation (Pérez-Morales et al., 2018), although it can be very effective in reducing risks under climate change (Thieken et al., 2016). Under high sea level rise, risk zoning can be more effective than hard defences (Andersson-Sköld et al., 2015).
		Emergency plans, training for evacuations, early warning systems	Require that the role and responsibilities of different administrative departments and organizations involved are well-defined, and that there is a clear plan on how to manage the different stages in the recovery process (Adedeji et al., 2019).
		Planned relocation	Higher resistance was found among seafront residents, second-home occupants, homeowners, elderly, retired, and multi-generation households (Dachary-Bernard et al., 2019; Rey-Valette et al., 2019; Seebauer and Winkler, 2020).

Sector	Risk and cause	Examples of adaptation options	Elements related to the implementation of adaptation options
	Clay-related subsidence due to increased/ extreme drought	Deeper foundations, trees or terraces around light buildings to keep humidity in soils and prevent ground motions	Clay-related subsidence risks can be managed by appropriate adaptation measures at building scales (*medium confidence*) (Pritchard et al., 2015)

Table Notes:

[1] Heatwave warnings and Heat Action Plans as means for adaptation are discussed in Section 13.7.2

Table SM13.15: Literature sources used in the assessment of feasibility and effectiveness of adaptation options for cities, settlements and key infrastructure in Europe (Figure 13.20)

		Effectiveness	**Feasibility**					
Impact type	Adaptation option		*Economic*	*Technological*	*Institutional*	*Socio-cultural*	*Ecological*	*Geophysical*
Reduction of thermal comfort due to increasing temperatures and extreme heat	Interventions in the building shell	(Tillson et al., 2013; Sajjadian et al., 2015; Ibrahim and Pelsmakers, 2018; Domínguez-Amarillo et al., 2019)	(Tillson et al., 2013; Sajjadian et al., 2015; Murtagh et al., 2019)	(Sajjadian et al., 2015)	(Ibrahim and Pelsmakers, 2018; Murtagh et al., 2019)	(Ibrahim and Pelsmakers, 2018; Murtagh et al., 2019)		(Tillson et al., 2013; Ibrahim and Pelsmakers, 2018; Domínguez-Amarillo et al., 2019)
	Ventilation	(Tillson et al., 2013; van Hooff et al., 2014; Dodoo and Gustavsson, 2016; Mulville and Stravoravdis, 2016; Hamdy et al., 2017; Zinzi et al., 2017; Heracleous and Michael, 2018; Ibrahim and Pelsmakers, 2018; Dino and Meral Akgül, 2019; Thomson et al., 2019)	(van Hooff et al., 2014; Murtagh et al., 2019)	(van Hooff et al., 2014)	(Tillson et al., 2013; Mulville and Stravoravdis, 2016; Murtagh et al., 2019)	(Tillson et al., 2013; van Hooff et al., 2014; Mulville and Stravoravdis, 2016; Ibrahim and Pelsmakers, 2018; Murtagh et al., 2019; Thomson et al., 2019)		(Tillson et al., 2013; van Hooff et al., 2014; Ibrahim and Pelsmakers, 2018)

		Effectiveness	**Feasibility**					
Impact type	Adaptation option		*Economic*	*Technological*	*Institutional*	*Socio-cultural*	*Ecological*	*Geophysical*
	Air conditioning	(Jenkins et al., 2014a; Dodoo and Gustavsson, 2016; Dino and Meral Akgül, 2019)	(Ferrara and Fabrizio, 2017; Thomson et al., 2017)			(Thomson et al., 2019)		(Jenkins et al., 2014a)
	Shading	(Tillson et al., 2013; van Hooff et al., 2014; Dodoo and Gustavsson, 2016; Zinzi et al., 2017; Ibrahim and Pelsmakers, 2018)	(Tillson et al., 2013; van Hooff et al., 2014; Murtagh et al., 2019)	(van Hooff et al., 2014)	(Murtagh et al., 2019; Thomson et al., 2019)	(Tillson et al., 2013; Ibrahim and Pelsmakers, 2018; Murtagh et al., 2019)		(van Hooff et al., 2014; Thomson et al., 2019)
	Green roofs, green walls	(Cameron et al., 2014; van Hooff et al., 2014; Virk et al., 2015; Carvalho et al., 2017a; de Munck et al., 2018)	(Cameron et al., 2014; Virk et al., 2015; Carvalho et al., 2017a; de Munck et al., 2018)	(Cameron et al., 2014; Carvalho et al., 2017a; de Munck et al., 2018)	(Cameron et al., 2014; Virk et al., 2014)	(Cameron et al., 2014; van Hooff et al., 2014; Virk et al., 2015; Carvalho et al., 2017a; Derkzen et al., 2017)	(Virk et al., 2015)	(van Hooff et al., 2014)
	Urban green spaces	(Emmanuel and Loconsole, 2015; Ward et al., 2016; Carvalho et al.,	(Carvalho et al., 2017a; de Munck et al., 2018)	(Carvalho et al., 2017a; de Munck et al., 2018)	(Emmanuel and Loconsole, 2015)	(Carvalho et al., 2017a; Derkzen et al., 2017; Thomson et al., 2019)	(de Munck et al., 2018)	(Emmanuel and Loconsole, 2015; Carvalho et al., 2017a; de Munck et

		Effectiveness	**Feasibility**					
Impact type	Adaptation option		*Economic*	*Technological*	*Institutional*	*Socio-cultural*	*Ecological*	*Geophysical*
		2017a; de Munck et al., 2018)						al., 2018; Thomson et al., 2019)
	Use of 'cool' paints and coatings	(Carnielo and Zinzi, 2013; van Hooff et al., 2014; Virk et al., 2014; Virk et al., 2015; Zinzi, 2016; Carvalho et al., 2017a)	(van Hooff et al., 2014; Virk et al., 2015; Carvalho et al., 2017a; Murtagh et al., 2019)	(Carnielo and Zinzi, 2013; Carvalho et al., 2017a)	(Virk et al., 2014)	(Carnielo and Zinzi, 2013; Virk et al., 2015; Murtagh et al., 2019)		(Zinzi, 2016)
	Escape to nearby non-urban destinations					(Juschten et al., 2019a; Juschten et al., 2019b)		
Loss of critical services due to heatwaves and drought	Improvements in cooling systems	(Jenkins et al., 2014a; Koch et al., 2014; Byers et al., 2015; Ferranti et al., 2016; Kingsborough et al., 2016; van Vliet et al., 2016b; Behrens et al., 2017; Bogmans et al., 2017)	(Koch et al., 2014; van Vliet et al., 2016b; Behrens et al., 2017; Bogmans et al., 2017; EEA, 2019a)	(Sieber, 2013; Ferranti et al., 2016)	(Jenkins et al., 2014a; Koch et al., 2014; Byers et al., 2015; Hendel et al., 2016; Kingsborough et al., 2016; Behrens et al., 2017)			(Sieber, 2013; Koch et al., 2014; van Vliet et al., 2016b; Behrens et al., 2017)

		Effectiveness	**Feasibility**					
Impact type	Adaptation option		*Economic*	*Technological*	*Institutional*	*Socio-cultural*	*Ecological*	*Geophysical*
	Shifting production to less water-intensive plants	(Khan et al., 2016)	(Khan et al., 2016; Behrens et al., 2017)	(Khan et al., 2016)	(Behrens et al., 2017)			
	Regulatory measures	(Eisenack, 2016)	(Eisenack, 2016)		(Eisenack, 2016)			
	Management measures	(Gaudard et al., 2013; Hendel et al., 2015; Ferranti et al., 2016; Kingsborough et al., 2016; Ranzani et al., 2018; Wang et al., 2019)	(Ferranti et al., 2016; Ranzani et al., 2018; Wang et al., 2019)	(Hendel et al., 2015; Kingsborough et al., 2016)	(Ferranti et al., 2016; EEA, 2019a; Palkowski et al., 2019)		(Hendel et al., 2015)	(Gaudard et al., 2013; Hendel et al., 2015)
	Use of heat-resilient materials	(Carnielo and Zinzi, 2013; EEA, 2019a; Wang et al., 2019)	(Carnielo and Zinzi, 2013; EEA, 2019a; Wang et al., 2019)	(Carnielo and Zinzi, 2013; EEA, 2019a; Wang et al., 2019)	(Carnielo and Zinzi, 2013; EEA, 2019a; Wang et al., 2019)	(Carnielo and Zinzi, 2013; EEA, 2019a; Wang et al., 2019)		
	Replace vulnerable infrastructure with resilient one	(van Slobbe et al., 2016; Wang et al., 2019)	(van Slobbe et al., 2016; Wang et al., 2019)					

Table SM13.16: Reported adaptation limits in Europe (Figure 13.21)

Technical limits

- Physical characteristics of the existing housing stock preventing high ventilation (Tillson et al., 2013)
- Limited efficacy of hard defences for high sea level rise (i.e. >1m)/ rapid rates of sea-level rise (e.g., above 1cm/year) (Umgiesser, 2020) [see also section 13.2 - Venice Box]
- Natural ventilation is limited by safety, noise, and air pollution concerns (Tillson et al., 2013; van Hooff et al., 2014; Mulville and Stravoravdis, 2016)
- Too large sediment volumes needed for beach nourishment (Galofré et al., 2016; Jiménez and Valdemoro, 2019)
- Wet-bulb temperature for snowmaking (Spandre et al., 2016; Hartl et al., 2018)
- Seawater cooling feasible only for coastal plants (Behrens et al., 2017)
- Management optimization not applicable to run-of-river hydropower plants (Gaudard et al., 2013)
- Automation for flood discharge not suitable for certain hydropower dams (EEA, 2020c)
- Water temperature caps can reduce thermal power availability and cause blackouts (Eisenack, 2016)

Socio-economic limits

- Low flood probability prohibits the pay-off of costly investments in home flood proofing (Poussin et al., 2015)
- Energy poverty limits the households' capacity to adapt to overheating (Sanchez-Guevara et al., 2019; Thomson et al., 2019)
- High investments needed for upgrading current drainage to new standards (EEA, 2020c)
- High installation costs for applying flood-proofing measures beyond critical substations (EEA, 2020a)
- No adaptation benefits from turning aerial transmission cables into underground ones in flood-prone areas (Sieber, 2013)

Environmental & regulatory limits

- Minimum Energy Performance standards covering only residential air-conditioners (Palkowski et al., 2019)
- Space constraints on green infrastructure for flood management (Liu and Jensen, 2018)
- Limited/no availability of free areas in higher altitudes and orographic constraints for expanding skiable corridors (Campos Rodrigues et al., 2018)
- Limited water resources for increasing snowmaking (Spandre et al., 2016; Scott et al., 2019; Steiger et al., 2020)
- Impossible inland shift of tourism and settlements due to coastal urbanization or geomorphology (Toimil et al., 2018)
- Lack of nearby alternative non-fresh water sources for plant cooling (Sieber, 2013)

Table SM13.17: Present status of planned and implemented adaptation in cities, energy sector, tourism sector, transport and industry in Europe (Table 13.1)

Sector	References
Cities	(Reckien et al., 2015; EEA, 2016b; Geneletti and Zardo, 2016; Buurman et al., 2017; Davis et al., 2018; Gedikli and Balaban, 2018; Reckien et al., 2018; CoM, 2019; Pietrapertosa et al., 2019; Bertoldi et al., 2020)
Energy	(EEA, 2018; EEA, 2019a; Gasho, 2019)
Tourism	(Gómez-Martín et al., 2014; Haanpää et al., 2015; Damm et al., 2017; Campos Rodrigues et al., 2018; Joye, 2018; Landauer et al., 2018; Tirado et al., 2019)
Transport	(Rotter et al., 2016; Battiston et al., 2017)
Industry and business	(Averchenkova et al., 2016; Herrmann and Guenther, 2017; Halkos et al., 2018; Schiemann and Sakhel, 2018; Aguinaldo et al., 2019; D'Orazio and Popoyan, 2019; CDSB, 2020; de Bruin et al., 2020; Feridun and Güngör, 2020; ECB, 2021a; ECB, 2021b)

SM13.6 Supplementary Material Supporting Section 13.7

Table SM13.18: Literature sources used in the assessment of climate sensitive infectious diseases (Figure 13.23)

Climate sensitive infectious disease	References
Tick-borne encephalitis (TBE) & borreliosis (Lyme)	(Jaenson and Lindgren, 2011; Rizzoli et al., 2011; Estrada-Pena et al., 2012; Jaenson et al., 2012; Medlock et al., 2013; Alkishe et al., 2017; Sykes and Makiello, 2017; Tokarevich et al., 2017; Daniel et al., 2018; Medlock et al., 2018; Semenza and Suk, 2018; Waits et al., 2018; Estrada-

	Pena and Fernandez-Ruiz, 2020; Nah et al., 2020; Rogovskyy et al., 2020; Vandekerckhove et al., 2021)
West Nile virus	(Semenza and Menne, 2009; Medlock et al., 2015; Paz, 2015; Proestos et al., 2015; Marini et al., 2016; Semenza et al., 2016; Vogels et al., 2017; Haussig et al., 2018; Vlaskamp et al., 2020; Marini et al., 2021; Rodriguez-Alarcon et al., 2021; Young et al., 2021)
Dengue, Chikungunya, Zika viruses	(Caminade et al., 2012; Bouzid et al., 2014; Schaffner and Mathis, 2014; Semenza et al., 2014; Kraemer et al., 2015; Cunze et al., 2016; Liu-Helmersson et al., 2016; Nsoesie et al., 2016; Rezza, 2016; Shepard et al., 2016; Stanaway et al., 2016; Caminade et al., 2017; Tjaden et al., 2017; Mascarenhas et al., 2018; Medlock et al., 2018; Semenza and Suk, 2018; Solimini et al., 2018; Tjaden et al., 2018; Liu-Helmersson et al., 2019; Messina et al., 2019; Metelmann et al., 2019; Ryan et al., 2019; Blagrove et al., 2020; Brugueras et al., 2020; Iwamura et al., 2020; Liu et al., 2020; Colon-Gonzalez et al., 2021; Oliveira et al., 2021; Ryan et al., 2021; Zeng et al., 2021)
Malaria	(Caminade et al., 2014; Murdock et al., 2016; Piperaki and Daikos, 2016; Hertig, 2019; Fischer et al., 2020b; Karypidou et al., 2020)
Vibriosis	(Baker-Austin et al., 2013; Escobar et al., 2015; Baker-Austin et al., 2017)

Table SM13.19: Literature sources used in the assessment of feasibility and effectiveness of adaptation options for mortality, morbidity, exposure, stress from heat in Europe (Figure 13.24).

		Effectiveness	**Feasibility**					
Impact Type	Adaptation Option		Economic	Technological	Institutional	Socio-cultural	Ecological	Geophysical
Heat	Behaviour change measures	(Khare et al., 2015; Hendel et al., 2017; Schuster et al., 2017)	(Hendel et al., 2017)	(Khare et al., 2015)	(Khare et al., 2015)	(Khare et al., 2015; Schuster et al., 2017)		
	Natural cooling	(Alessandrini et al., 2019)		(Alessandrini et al., 2019)		(Alessandrini et al., 2019)		
	Building interventions	(Åström et al., 2017; Taylor et al., 2018; Macintyre and Heaviside, 2019; Murtagh et al., 2019)	(Macintyre and Heaviside, 2019)	(Åström et al., 2017; Taylor et al., 2018; Macintyre and Heaviside, 2019)		(Åström et al., 2017; Macintyre and Heaviside, 2019)		(Fallmann et al., 2013)
	Green infrastructures	(Richter, 2016; Taylor et al., 2018; Rotzer et al., 2019; Venter et al., 2020)	(Venter et al., 2020)	(Richter, 2016; Taylor et al., 2018; Rotzer et al., 2019; Venter et al., 2020)	(Venter et al., 2020)	(Taylor et al., 2018; Venter et al., 2020)	(Rotzer et al., 2019; Venter et al., 2020)	(Fallmann et al., 2013; Taylor et al., 2018; Rotzer et al., 2019; Venter et al., 2020)
	Heat proof land management	(Fallmann et al., 2013; Åström et al., 2017; Montazeri et al., 2017)		(Åström et al., 2017; Montazeri et al., 2017)	(Donner et al., 2015; Åström et al., 2017)		(Åström et al., 2017)	(Fallmann et al., 2013; Donner et al., 2015; Montazeri et al., 2017)
	Heat health action plans	(Gasparrini et al., 2015; Carmona et al., 2016; De'Donato et al., 2018)		(Gasparrini et al., 2015; Carmona et al., 2016; De'Donato et al., 2018; Reischl et al., 2018; Morabito et al., 2019)	(De'Donato et al., 2018; Reischl et al., 2018)	(Gasparrini et al., 2015; De'Donato et al., 2018; Reischl et al., 2018; Morabito et al., 2019)	(De'Donato et al., 2018; Casanueva et al., 2019; Morabito et al., 2019)	
	Bundle of options	(Åström et al., 2017; Guo et al., 2018; Díaz et al., 2019)	(Díaz et al., 2019)	(Díaz et al., 2019)				(Díaz et al., 2019)

SM13.7 Supplementary Material Supporting Section 13.8

Table SM13.20: References supporting the examples of losses and damages to vulnerable livelihoods in Europe, differentiating for different categories of non-economic loss and damage (Table 13.2)

Example of losses and damages	**Reference**
Loss of livelihood, culture, health and wellbeing of the Sámi and the Nenets.	(Arctic Council, 2013; Forbes et al., 2016; Hayashi, 2017; Huntington et al., 2017; Mikhaylova, 2018; Mustonen, 2018; Inuit Circumpolar Council, 2020; Feodoroff, 2021)
Loss of key species in high-Arctic freshwater habitats, **proliferation of introduced species** and **disruption of local food systems** in Greenland, Finland, Sweden, NW Russia and Scotland.	(Mustonen et al., 2018; Post et al., 2019; Frainer et al., 2020; Mustonen and Huusari, 2020; Feodoroff, 2021; Mustonen et al., 2021a; Mustonen et al., 2021b)
Warmer winters lead to **loss of income from ice fishing** and **cultural heritage** in Finland.	(Mustonen, 2014; Mustonen and Huusari, 2020)
Changes to marine food web results in **loss of Indigenous knowledge** and **food insecurity** in Greenland.	(Hayashi, 2017; Pecl et al., 2017; Hayashi and Walls, 2019; Inuit Circumpolar Council, 2020)
Reduced yields on managed alpine grasslands **decreases the self-sufficiency of pastoral livestock farming** in the Austrian, French and Swiss Alps	(Brunner et al., 2019; Deléglise et al., 2019 ; Lavorel et al., 2019; Lavorel et al., 2020)
Reduced yields on semi-natural grasslands, compromising livestock feeding in winter, and ultimately **decreasing viability of pastoralism** in the Spanish Pyrenees	(López-i-Gelats et al., 2016; Fernández-Giménez and Ritten, 2020)
Retreating glaciers and changes in the landscape lead to **loss of identity, culture and self-reliance** in the Italian Alps (Alto Adige)	(Jurt et al., 2015a; Jurt et al., 2015b)
Drought results in a **reduction of provisioning** (water) **and regulating services** (protection against floods) in Western and Eastern Alps, Iberian Mountains, Dinaric Mountains	(Leitinger et al., 2015; Mina et al., 2017; Schirpke et al., 2017; Strasser et al., 2019)
Increase of sea temperature leads to **shifts in distribution of cold water species**, reducing productivity at lower latitudes. **Artisanal fisheries** in Southern European coastal areas (Mediterranean) that rely on local, nearshore stocks can have difficulties to adapt	(Lloret et al., 2018)

Table SM13.21: References supporting figure 13.16 "Cumulative impacts of climate and land use change on reindeer herding as a traditional, semi-nomadic Sámi livelihood"

Indicator	**References**
Boundaries of reindeer herding areas in Sweden	Sámi Parliament in Sweden (2020)
Amount of snow	(Ranasinghe et al., 2021)
Unstable ice conditions	(Forbes et al., 2016; Mallory and Boyce, 2018)
Frequent freeze thaw cycles	(Johansson et al., 2011; Hansen et al., 2014; Bokhorst et al., 2016; Rasmus et al., 2018)

Indicator	References
Late snow melting during spring	(Meredith et al., 2019)
Heatwaves during summer	(Skarin et al., 2010; Furberg et al., 2011; Löf, 2013; Löf, 2014; Meredith et al., 2019; Rosqvist et al., 2021)
Spread of new diseases	(Omazic et al., 2019)
Insect harassment	(Mallory and Boyce, 2018; Tryland et al., 2019)
Psychological stress	(Kaiser et al., 2010; Furberg et al., 2011; Stoor, 2016)
Workload and costs	(Furberg et al., 2011; Löf, 2013; Löf, 2014; Rosqvist et al., 2021)
Conflicts between herding communities and developers, authorities and members of local communities about the desirability of competing land uses	(Lawrence, 2014; Sehlin MacNeil, 2015; Lawrence and Kløcker Larsen, 2017; Persson et al., 2017; Beland Lindahl et al., 2018)
Self-determination and adaptive capacity	(Brännlund and Axelsson, 2011; Löf, 2013; Brännström, 2017; Allard, 2018; Larsen and Raitio, 2019)
Mining	(Herrmann et al., 2014b; Eftestøl et al., 2019; Lawrence and Kløcker Larsen, 2019; Österlin and Raitio, 2020)
Hydropower	(Össbo and Lantto, 2011; Össbo, 2018)
Forestry	(Kivinen et al., 2012; Sandström et al., 2016; Fischer et al., 2020a)
Wind power	(Skarin et al., 2015; Skarin and Alam, 2017; Österlin and Raitio, 2020)
Tourism	(Nellemann et al., 2000; Skarin and Åhman, 2014; Olsen, 2016)

SM13.8 Supplementary Material Supporting Section 13.10

Table SM13.22: Detected changes and attribution (D&A) of climate-related impacts on land and in the ocean (Figure 13.29).

Assessment based on peer reviewed literature in this chapter that reported observed evidence with at least 90% significance and usually with 95% significance or more.

Assessment statement	Supporting References
Forest growth and production has been influenced by temperature and moisture conditions combined over the last centuries. The consequences of climate change differed regionally, especially along the south to north axis	(Pretzsch et al., 2014; Reyer et al., 2014; Seidl et al., 2014; Gazol et al., 2015a; Keenan et al., 2016; Reich et al., 2016; Tian et al., 2016; Alrahahleh et al., 2017; Ballantyne et al., 2017; Zlatanov et al., 2017; Humphrey et al., 2018; Marqués et al., 2018; Stocker et al., 2018; Vitali et al., 2018; Carnicer et al., 2019a; Ciais et al., 2019; Green et al., 2019; Yuan et al., 2019; Brodribb et al., 2020).
Tundra vegetation growth rate and shrub height have been accelerated by climate change	(Belonovskaya et al., 2016; Martin et al., 2017).

Assessment statement	Supporting References
Drought consequences in the Mediterranean region showed significant increase of adverse effects, and outside the southern region effects of drought varied considerably	(Fantappié et al., 2011; Giuntoli et al., 2013; Yigini and Panagos, 2016; Potopová et al., 2017; Stagge et al., 2017; Samaniego et al., 2018; García-Herrera et al., 2019; Spinoni et al., 2019; Zhou et al., 2019).
Crops decreased due to temperature related regional changes with variable regional impact in Europe, and optimal conditions of some crops moved northwards	(Garcia-Mozo et al., 2015; Long et al., 2016; Ceglar et al., 2017; Potopová et al., 2017; Zhao et al., 2017; Pérez-Domínguez and Fellmann, 2018; Webber et al., 2018; Di Lena et al., 2019).
River floods have had increasing damaging effects in central Europe, but decreased in other regions	(Alfieri et al., 2015a; Polemio and Lonigro, 2015; Ljungqvist et al., 2016; Blöschl et al., 2017; Kundzewicz et al., 2017; Paprotny et al., 2018; Berghuijs et al., 2019; Blöschl et al., 2019; Ganguli and Merz, 2019; Lenderink et al., 2019; Umgiesser, 2020).
Wildfire effects are jointly influenced by climate variables such as drought and temperature, but they are also highly influenced by management	(Moriondo et al., 2006; Moreno et al., 2014; Turco et al., 2014; Jolly et al., 2015; Tedim et al., 2015; Turco et al., 2016; de Rigo et al., 2017a; Turco et al., 2017; Turco et al., 2018b; Michetti and Pinar, 2019).
Marine heatwaves induced mass mortality of sessile life forms, and such episodes have increased in frequency	(Garrabou et al., 2009; Munari, 2011; Rivetti et al., 2014; Smale et al., 2015; Rubio-Portillo et al., 2016; Oliver et al., 2018; Darmaraki et al., 2019; Holbrook et al., 2019; Smale et al., 2019a).
Terrestrial species relocation rate towards higher latitude and altitude have increased	(Scherrer and Körner, 2011; Oliver et al., 2015; Melero et al., 2016; Stephens et al., 2016; Wiens, 2016; Bowler et al., 2017; Spooner et al., 2018; Lehikoinen et al., 2019a; van Klink et al., 2020a).
Marine species relocation from warm waters to previously colder but warming waters increased	(Fossheim et al., 2015; Hiddink et al., 2015; Montero Serra et al., 2015; van der Kooij et al., 2016; Chivers et al., 2017; García-Molinos et al., 2017; Cozzi et al., 2019; Vilà-Cabrera et al., 2019).
Coastal flood damaging effects increased.	(Haigh et al., 2011; Wahl et al., 2015; Malagon Santos et al., 2017; Garnier et al., 2018; Fernández-Montblanc et al., 2020; Umgiesser, 2020)
Phenology changes were well documented in AR5, and later literature have confirmed the trends	(Hassall et al., 2007; Visser et al., 2012; Karlsson, 2014; Thackeray et al., 2016b; Mayor et al., 2017; Cohen et al., 2018b; Lehikoinen et al., 2019b, Ettinger et al 2020; Menzel et al 2020).
Vector borne diseases have expanded northwards	(Daniel et al., 2003; Jaenson et al., 2012; Medlock et al., 2013; Jore et al., 2014; Tokarevich et al., 2017; Semenza and Suk, 2018).
Winter tourism has experienced decreased potential due to reduced snow cover and reliability of natural snow, with severity of loss highest at low altitudes	(Falk, 2015; Falk and Vanat, 2016; Klein et al., 2016; Beniston et al., 2018; Falk and Lin, 2018; Schöner et al., 2019). Rain on snow event frequency have increased (Beniston and Stoffel, 2016).
Damages from thaw of permafrost have been detected in a large range of societally important infrastructure, such as buildings and roads	(Stoffel et al., 2014; Porfiriev et al., 2017; Ravanel et al., 2017; Beniston et al., 2018; Duvillard et al., 2019).
Energy Demand for cooling has increased and for heating has decreased due to increasing temperatures	(De Rosa et al., 2015; Spinoni et al., 2015; EEA, 2017a policies and practices)
Macroeconomic damages for Europe have been detected	(Burke et al., 2015; Diffenbaugh and Burke, 2019).
Shoreline erosion is detected but literature is limited	(Castelle et al., 2018; Mentaschi et al., 2018).

Assessment statement	Supporting References
Aquatic species relocation includes expansion northwards, which in the southern region implies tropicalization	(Zhang et al., 2017; Monchamp et al., 2018; Kärcher et al., 2019; van Klink et al., 2020a).
Heatwaves induced mortality at increasing frequency and severity	(Shaposhnikov et al., 2015; Morabito et al., 2017; Vogel et al., 2019; Vicedo-Cabrera et al., 2021).
Ocean acidification combined with warming affects several aspects of marine commercial gain	(Lacoue-Labarthe et al., 2016; Fernandes et al., 2017).
Fisheries specimen size distribution changed. Frequency of small specimen size in increased in southern regions of European waters	(Fortibuoni et al., 2015; Gamito et al., 2015; Teixeira et al., 2016; Ding et al., 2017; Ojea et al., 2017; Free et al., 2019; Stecf, 2019).
Miscellaneous effects with limited evidence were not been included in figure 13.29. Several lone standing examples of effects that can be attributed to climate change have been adequately reported	For example increase in groundwater heavy metal contamination from fractured aquifers (Bondu et al., 2016), effects in livestock (Handisyde et al., 2017; Rojas-Downing et al., 2017), pathogen sensitivity (McIntyre et al., 2017; Moretti et al., 2019), and heat damage to railway tracks (Ferranti et al., 2018).

Table SM13.23: References for assessment of macroeconomic damages and gains for selected climate risks, measured by GDP and welfare for 1.5°C GWL and 3°C GWL relative to no additional warming (Figure 13.33).

*Only larger European subregions are covered; ** single country or subset of countries;

Risks	GWL	References
Change in agricultural yields	1.5°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
	3°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
Change in labour productivity	1.5°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
	3°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
Change in energy demand	1.5°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al.,

Risks	GWL	References
		2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
	3°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
Change in mortality due to heat	1.5°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
	3°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
Damage to economic sectors from water scarcity and drought	1.5°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
	3°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
Change in energy supply	1.5°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
	3°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
Damage to infrastructure from coastal flooding	1.5°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al.,

Risks	GWL	References
		2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
	3°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
Damage to infrastructure from inland flooding	1.5°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)
	3°C	(Faust et al., 2015; De Cian et al., 2016; Pycroft et al., 2016; Roson and Sartori, 2016; Aaheim et al., 2017; Koopman et al., 2017; Roson and Damania, 2017; Takakura et al., 2017; Dottori et al., 2018; Szewczyk et al., 2018; Dellink et al., 2019; Koks et al., 2019; Bosello et al., 2020; Knittel et al., 2020; Parrado et al., 2020; Szewczyk et al., 2020; Teotónio et al., 2020; García-León et al., 2021)

SM13.9 Supplementary Material Supporting the Feasibility and Effectiveness Assessment

Background

The assessment aimed to provide an overview of the current knowledge of the feasibility and effectiveness (F&E) of selected adaptation options for key climate risks in Europe, and inform the design of illustrative adaptation pathways in section 13.10.2 (see SM13.11). Feasibility is understood as the potential for an adaptation option to be implemented. Feasibility depends on geophysical, environmental-ecological, technological, economic, socio-cultural and institutional factors that enable or constrain the implementation. Effectiveness refers to the potential the option to reduce risk compared to a baseline (see WGII Glossary).

Figure 1 below presents the main steps taken in the F&E assessment. The evidence presented in chapter 13 figure 13.6 (section 13.2.2), figure 13.14 (section 13.5.2), figure 13.20 (section 13.6.2), and figure 13.24 (section 13.7.2) is the result of the available scientific evidence presented in the Supplementary Materials (Table SM13.1, Table SM13.5, Table SM13.15, Table SM13.19) and expert interpretation of these data. The approach was largely similar to the IPCC AR6 Special Report: Global Warming of 1.5 ºC (Chapter 4), and further detailed in Singh et al. (2020).

Scientific articles were collected from a range of sources including the Global Adaptation Mapping Initiative (Berrang-Ford, 2021), focused literature searches by the author team including CAs, and references suggested by reviewers. The assessment focused on those studies that empirically assessed (i.e. using case studies, models, experiments) the feasibility and effectiveness of adaptation options, thereby excluding conceptual and opinion articles. Only articles that explicitly considered measures to adapt to the observed impacts or projected risks of climate change were included to ensure conceptual consistency of the assessment, as is common in most systematic assessments on climate change adaptation (Berrang-Ford et al., 2015). Moreover, articles were only included when they reported a clear link between the adaptation option and one or several of the feasibility and effectiveness assessment criteria. Articles listing general enabling and constraining factors to adaptation within a sector in general, for example, were not included in the F&E assessment. Grey literature and articles not in the English langue were not included due to time and resource constraints. These may have created a bias in the data sets used for the assessment.

Detailed methods of the assessment approach and calculation of the scores for individual indicators and aggregation to the six feasibility dimensions can be found in Singh et al (2020). The results visualized in the figures is the combination of scientific evidence and discussions among experts in the author team. Contributing authors were invited to participate when expertise within the Lead Author team was limited.

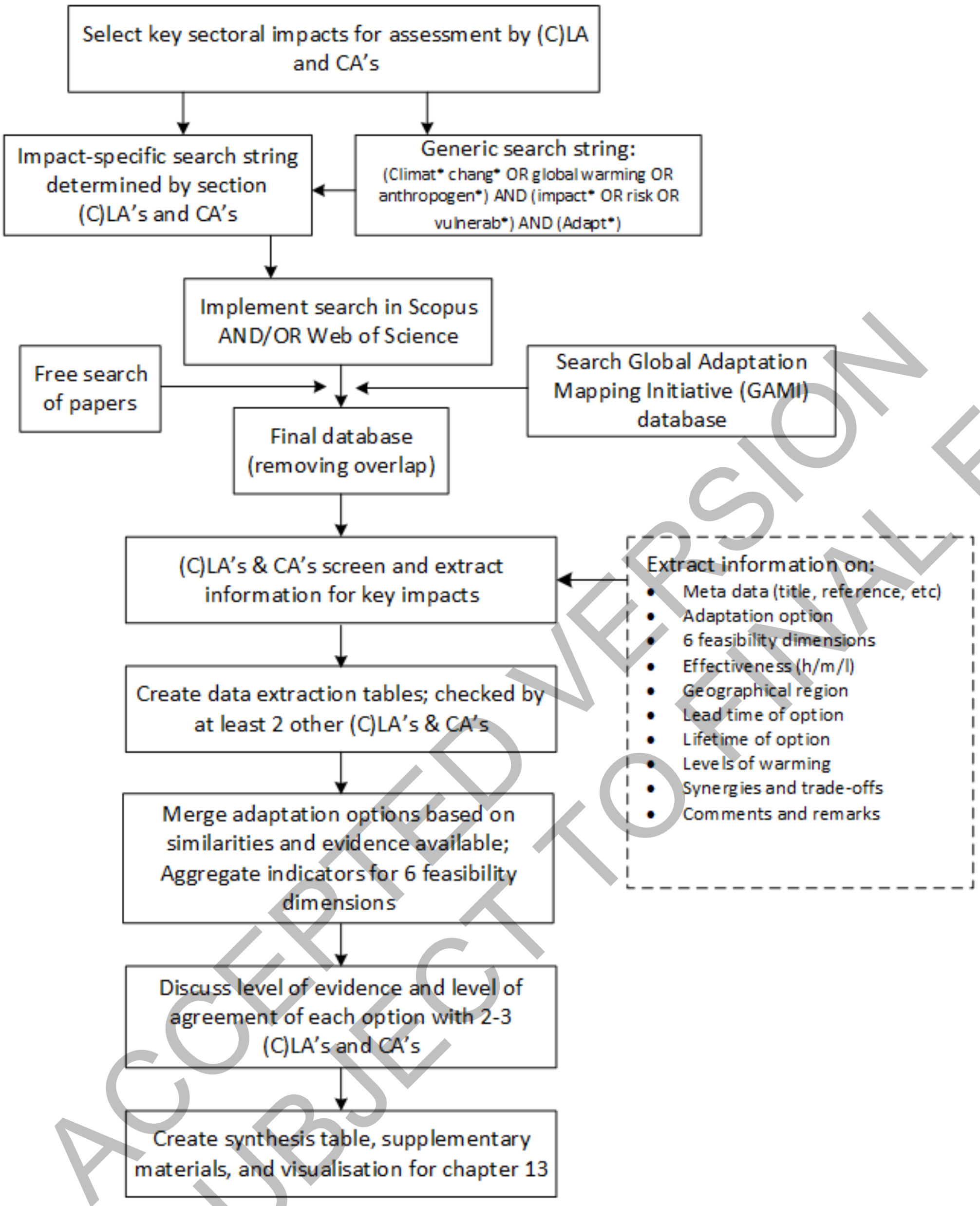

Figure SM13.1: General workflow for assessing effectiveness and feasibility of adaptation options

SM13.10 Supplementary Material Supporting the Key Risks and Burning Embers Assessments

The detailed methodology for the key risk assessment is described in Chapter 16. Lead and Contributing Authors in Chapter 13 have been assigned to assess the key risks literature based on their expertise and contributions to the chapter. Data were extracted from the references listed in Table SM13.22 and entered in 5 different excel sheets (2 excel sheet for key risk 1 and one for each of the other key risks): reference, IPCC sub-regions, RCPs or any other corresponding climate scenarios, time periods, warming (GSAT) from pre-industrial derived according to the common climate dimensions (see Cross Chapter Box CLIMATE in Chapter 1), climatic impact drivers (Ranasinghe et al., 2021), SSPs (if available), climate models and type of simulations, impact models, sector(s) affected, risk metric, risk consequences, comments.

Following the data extraction, the key risk teams participated in expert elicitation workshops to reach consensus on the risk and temperature transition levels to feed into the construction of the burning ember diagrams in figures 13.30-13.34 (see Zommers et al., 2020). The methodology is provided in Section SM13.11 and it was slightly adapted for the assessments in this chapter. Results are summarised in Tables SM13.25-SM13.31 below.

Table SM13.24: List of references supporting the assessment of the key risks in Section 13.10.2.

KR1: Risks of human mortality and heat stress and of ecosystems disruptions due to heat extremes and increase in average temperatures	**References**
Human health	(Frolov et al., 2014a; Jenkins et al., 2014b; Barbosa et al., 2015; Åström et al., 2017; Forzieri et al., 2017; Gasparrini et al., 2017; Hamdy et al., 2017; Hunt et al., 2017; Kendrovski et al., 2017; Mora et al., 2017; Cellura et al., 2018 2019, Mortality attributable to high temperatures over the 2021–2050 and 2051–2100 time horizons in Spain: Adaptation and economic estimate; Forzieri et al., 2018; Guo et al., 2018; Heracleous and Michael, 2018; Arnell et al., 2019; Revich et al., 2019 indicators, predictions; Rohat et al., 2019; Casanueva et al., 2020; Lee et al., 2020; Vanos et al., 2020; Ebi et al., 2021)
Marine ecosystems	(Roebeling et al., 2013; Albouy et al., 2014; Brodie et al., 2014; Carstensen et al., 2014; Frolov et al., 2014a; Herrmann et al., 2014a; Maugendre et al., 2014; Hennige et al., 2015; Serra et al., 2015; Wall et al., 2015; Cheung et al., 2016; García Molinos et al., 2016; Holt et al., 2016; Krumhansl et al., 2016; Lam et al., 2016; Ragazzola et al., 2016; Spencer et al., 2016; Stiasny et al., 2016; Thackeray et al., 2016b; Fernandes et al., 2017; Galli et al., 2017; Narita and Rehdanz, 2017; Semenza et al., 2017; Thomsen et al., 2017; Townhill et al., 2017; Wang et al., 2017b; Benedetti et al., 2018; Corrales et al., 2018; Gao et al., 2018; Jokinen et al., 2018; Mangi et al., 2018; Riebesell et al., 2018; Sswat et al., 2018b; van der Spek, 2018; Wang et al., 2018; Chefaoui et al., 2019; de la Hoz et al., 2019; Durant et al., 2019; Edelgeriev, 2019; Herrera et al., 2019; Lotze et al., 2019b; Moullec et al., 2019; Petrik et al., 2019; Richon et al., 2019; Roggatz et al., 2019; Spivak et al., 2019; Bryndum-Buchholz et al., 2020; Clark et al., 2020; Maltby et al., 2020; Xi et al., 2021)
Terrestrial ecosystems	(Gallego-Sala et al., 2010; Perch-Nielsen et al., 2010; Dury et al., 2011; San-Miguel-Ayanz et al., 2012; Filipe et al., 2013; Matzarakis et al., 2013; Steiger and Stötter, 2013; Bedia et al., 2014; Frolov et al., 2014a; Markovic et al., 2014; Matzarakis et al., 2014; Oliver et al., 2015; Urban, 2015; Wu et al., 2015a; Brambilla et al., 2016; Grillakis et al., 2016; Polce et al., 2016; Scott et al., 2016; Thackeray et al., 2016b; Camia et al., 2017; EEA, 2017a; Pecl et al., 2017; Sáenz-Romero et al., 2017; Vazquez et al., 2017; Vermaat et al., 2017; Dyderski et al., 2018; Ceglar et al., 2019; Ferretto et al., 2019; Jakoby et al., 2019a; Lotze et al., 2019b; Berberoglu et al., 2020; Feyen et al., 2020; Gianinetto et al., 2020; Qiu et al., 2020; Wamelink et al., 2020; Urvois et al., 2021; Xi et al., 2021)

KR2: Risk of losses in crop production, due to compound heat and dry conditions, and extreme weather	**References**
	(Caffarra et al., 2012; Sutton et al., 2013; Deryng et al., 2014; Donatelli et al., 2015; Reidsma et al., 2015; Bird et al., 2016; Castellanos-Frias et al., 2016; Knox et al., 2016; Webber et al., 2016; Diogo et al., 2017; Holman et al., 2017; Nielsen et al., 2017; Popp et al., 2017; Siebert et al., 2017; Williges et al., 2017; Ben-Ari et al., 2018; Parent et al., 2018 with an appropriate use of the genetic variability of flowering time; Ruiz-Ramos et al., 2018; Szewczyk et al., 2018; Webber et al., 2018; Ceglar et al., 2019; Chen et al., 2019; EEA, 2019b; Grillakis, 2019; Moretti et al., 2019; Papadimitriou et al., 2019; Toreti et al., 2019; Feyen et al., 2020; Jäger et al., 2020; Huttunen et al., 2021 societal and manure recycling scenarios; Pedde et al., 2021)
KR3: Risk of water scarcity to multiple interconnected sectors	**References**
	(Blauhut et al., 2015; Collet et al., 2015; Kebede et al., 2015; Papadaskalopoulou et al., 2015b; Blauhut et al., 2016; Gain et al., 2016; Gampe et al., 2016; Schleussner et al., 2016; Stahl et al., 2016; Koopman et al., 2017; van Vuuren et al., 2017; Byers et al., 2018; Greve et al., 2018; Iglesias et al., 2018; Manouseli et al., 2018; Naumann et al., 2018; Tobin et al., 2018b; Arnell et al., 2019; Garnier and Holman, 2019; Harrison et al., 2019; Koutroulis et al., 2019; Morote et al., 2019; Papadimitriou et al., 2019; Bisselink et al., 2020; Cammalleri et al., 2020; Teotónio et al., 2020; Kebede et al., 2021; Naumann et al., 2021)
KR4: Risks to people, economies and infrastructures due to coastal and inland flood hazards	**References**
Coastal flooding	(Ciscar et al., 2014; Marzeion and Levermann, 2014; Clark et al., 2016; Pycroft et al., 2016; Reimann et al., 2018; Vousdoukas et al., 2018; Arnell et al., 2019; Harrison et al., 2019; Vousdoukas et al., 2020; Haasnoot et al., 2021)
Inland flooding	(Jongman et al., 2014; Alfieri et al., 2015b; Alfieri et al., 2016a; Alfieri et al., 2016b; Alfieri et al., 2017; Alfieri et al., 2018; Ciscar et al., 2018; Dottori et al., 2018; Paprotny et al., 2018; Arnell et al., 2019; Harrison et al., 2019; Papadimitriou et al., 2019; Dottori et al., 2020 EUR 29955 EN; Hosseinzadehtalaei et al., 2020; Lange et al., 2020; Merz et al., 2021 impacts and patterns of disasterous river floods)

Table SM13.25: Transition and confidence levels for the risks of human mortality and heat stress due to heat extremes and increase in average temperature (Figure 13.29).

Risk level with present to medium adaptation, including SSP2-SSP4	**Range of temperature transitions**	**Confidence level for the transition**	**Explanation (text + references)**
Undetectable to moderate risk	0.73-0.85°C GWL	*High*	The range and confidence are supported by evidence from the detection and attribution assessment (Figure 13.27; Table SM13.1) (Vicedo-Cabrera et al., 2021). The range reflect warming between 1995-2014 as reported in WGI Cross-Chapter Box 2.3. Furthermore, the climate impact drivers (both mean air temperature and extremes) emerged already in the historical period with *medium confidence* (AR6 WGI, Figure 12.7). Detected to date (from D&A assessment 13.10.1): (Shaposhnikov et al., 2015; Morabito et al., 2017; Vogel et al., 2019; Vicedo-Cabrera et al., 2021)
Moderate to high risk	1.6-2.2°C GWL	*High*	The magnitude of consequences associated to a number of risks metrics such as mortality and population exposure to heat extremes all increase beyond 1.5°C GWL. (Naumann et al., 2020a) shows an increase already at 1.5 but there is little less evidence and consensus that a transition happens before or at 1.5°C GWL. The risk also increases less rapidly for every indicator or at least there is little consensus in the literature. It is higher and more likely in Southern regions but not everywhere. Magnitude of risk consequences reported in the literature to support this transition: - Excess mortality attributable to climate change: 1.5%-1.67% (Gasparrini et al., 2017) (NEU, WCE, SEU). - Proportion of the European population at risk of heat stress: 161 million (Rohat et al., 2019) in EU27+UK. - Additional attributable death compared to no climate change from value in brackets: 30867 (17384) in Europe. - Increase in heatwave excess deaths in SEU, WCE and NEU with highest increase in NEU (Guo et al., 2018) - People annually exposed to a 50-year heatwave (present value in brackets): 176 Mi (9.6 Mi) and heat fatalities per year (present value in brackets): 52182 (2752) (Naumann et al., 2020a) Literature supporting this transition: (Forzieri et al., 2017; Gasparrini et al., 2017; Hunt et al., 2017; Kendrovski et al., 2017; Guo et al., 2018; Rohat et al., 2019; Lee et al., 2020; Naumann et al., 2020b)

High to very high risk	2.9-3.5°C GWL	*Medium*	Some studies point at a transition at higher levels whereas other at lower levels. However, the risk become more persistent and increases in every region as well as its likelihood increases. The ability to adapt is not completely excluded but assuming current adaptation condition or SSP2/SSP4, very high risk will be realized under 3°C GWL. Magnitude of risk consequences reported in the literature to support this transition: At 3°C GWL: - Proportion of the European population at risk of heat stress compared to the reference period 1982-2005 in brackets: 216 mi / 48.4% (2.1 mi / 0.4%) (Rohat et al., 2019) - Extreme heat deaths per 10 mi inhabitants (1981-2010): 2817 (54.7) (Forzieri et al., 2017) - Heat fatalities per year in the order of 90'000 (Naumann et al., 2020a) - Extreme heat deaths per 10 mi inhabitants 2816.9 in EU27+UK (Forzieri et al., 2017) 3.5-4°GWL: - Attributable death compared to no climate change: 117333 (16303) (Kendrovski et al., 2017) - Increase in heatwave excess deaths compared to present warming levels: 200-280% (highest increase in NEU) Literature supporting this transition: (Forzieri et al., 2017; Kendrovski et al., 2017; Rohat et al., 2019; Casanueva et al., 2020; Naumann et al., 2020b).
Risk level with high adaptation, including SSP1	**Range of temperature transitions**	**Confidence level for the transition**	**Explanation (text + references)**
Undetectable to moderate risk	0.7-1.1°C GWL	*High*	The range and confidence level are supported by evidence from the detection and attribution assessment (Figure 13.29; Table SM13.1) (Vicedo-Cabrera et al., 2021). The ranges reflect warming between 1995-2014 as reported in WGI Cross-Chapter Box 2.3. Furthermore, the climate impact drivers (both mean air temperature and extremes) emerged already in the historical period with *medium confidence* (Figure 12.7, Ranasinghe et al., 2021). Detected to date (from D&A assessment 13.10.1): (Shaposhnikov et al., 2015; Morabito et al., 2017; Vogel et al., 2019; Vicedo-Cabrera et al., 2021); additional evidence from the F&E assessment (Tables SM13.5.3, SM13.6.2).

Moderate to high risk	2.5-3.8°C GWL	*Medium*	This transition is based on a body of literature which considers the adaptation needed to maintain the number of deaths at current level or SSP1 conditions and that confirms the mortality rates as well as the people at risk of heat stress are much lower than in the case with present to moderate adaptation (Åström et al., 2017; Guo et al., 2018 Quantifying excess deaths related to heatwaves under climate change scenarios: A multicountry time series modelling study; Díaz et al., 2019; Rohat et al., 2019). For example, Åström, (Åström et al., 2017) calculate the rate of adaptation needed at around 2°GWL to maintain the number of deaths at present level and found this rate to be over 75%. Various caveats concern the assumptions of full acclimatization above 3°C and the existence of possible physiological limits (Vanos et al., 2020). Ebi (2021) find that the burning ember for heat related mortality and morbidity with high adaptation (e.g. SSP1) has a transition between 2-3°C GWL. Considering that this is a global study and taking into account the evidence on high adaptation, we conclude that the transition level is somewhere above 2 °C but below 4°C (Åström et al., 2017; Guo et al., 2018; Díaz et al., 2019). Additional evidence from the F&E assessment (Tables SM13.5.3, SM13.6.2).
High to very high risk	Does not reach this level		There is little evidence that the risk will reach this level assuming full adaptation because the adaptation potential is still higher in high adaptation scenarios in several regions (NEU) for example and in agreement with the burning embers in (Ebi et al., 2021). We concluded that under a high adaptation scenario, the risks do not reach this threshold.

Table SM13.26: Transition and confidence levels for the risks of marine ecosystems disruptions due to heat extremes and increase in average temperatures

Risk Level	**Range of temperature transitions**	**Confidence level for the risk-level transition**	**Explanation (text + references)**
Undetectable to moderate	0.9-1.7°C GWL	*Medium*	A comprehensive summarizing assessment across all impacts/risks on/for marine systems is impaired by the uneven distribution of available information on their levels and development driven by RCP scenarios at 1.7°C GWL, 2.5 °C GWL and above 4 °C GWL making the determination of transitions challenging. Start the transition around or less 1°C to 1.7°C with *medium confidence* Detected to date (selected from D&A assessment 13.10.1): – Marine heatwaves have increased in frequency and induced mass mortality (Garrabou et al., 2009; Munari, 2011; Rivetti et al., 2014; Rubio-Portillo et al., 2016; Smale et al., 2019b). – Marine species relocation (Fossheim et al., 2015; Hiddink et al., 2015; Montero Serra et al., 2015; van der Kooij et al., 2016; Chivers et al., 2017; Cozzi et al., 2019). – Detected changes in range expansion (Birchenough et al., 2015), species distribution and species phenologies leading to a change from plankton communities (Burrows et al., 2019) to subtropicalisation of European pelagic fish communities (Montero Serra et al., 2015)

			– Fisheries change in size of catch (Fortibuoni et al., 2015; Gamito et al., 2015; Teixeira et al., 2016; Ding et al., 2017; Ojea et al., 2017; Free et al., 2019; Stecf, 2019). Projected risk (further information in Figure 13.11) 1.7°C GWL: Increasing risks across systems, from habitat losses to biodiversity and ecosystem services; while observed impacts were/are most severe first in the MED, at this GWL risks a projected to extend to transitional waters. – 13% Diversity losses YB19, 25- 40% loss in animal biomass (Bryndum-Buchholz et al., 2019; Lotze et al., 2019a) – 20% loss coastal wetland, 7% loss in ecosystem value (Roebeling et al., 2013) – 60% habitat reduction for fish in the Mediterranean (Clark et al., 2020), impacting commercially important fish e.g. anchovy (Raybaud et al., 2017) – Loss of 20% to 40% change in catch potential shellfish and -20 fish (Lam et al., 2016; Fernandes et al., 2017)
Moderate to high	2-2.2°C GWL	*Low*	Note: Confidence level is *low* because there is a distinct gap in information on risk development for warming levels between 1.7 and 2.5 °C GWL At 2°C GWL: – Increase in area suitable for viruses (Semenza et al., 2017) – Increase in likelihood of marine heatwaves (Frölicher et al., 2018)
High to very high	2.5-3.0°C GWL	*High*	At 2.5°C GWL: – Strong risks across shallow water ecosystems due to the combined warming and SLR: Projected 28% loss in coastal wetlands, 10% ecosystem value, (Roebeling et al., 2013); regionally up to 80% loss in wetland (Spencer et al., 2016) – Drowning of intertidal flats in TEUS (van der Spek, 2018) – changes in species dominance (Moullec et al., 2019), – diversity loss 20% in TEUS and 40% in NEUS (García Molinos et al., 2016) – Losses in shellfish biomass in TEUS increase to -40-50 locally up to -80% in response to warming and resulting habitat loss with significant economic losses (Fernandes et al., 2017; Galli et al., 2017; Mangi et al., 2018), 30% fin fish (Cheung et al., 2016; Lam et al., 2016) and loss of habitat for economically important shellfish in the SEUS (Mangi et al., 2018) – decrease in potential catch of cod and other economically important species (Maltby et al., 2020) – needs change in consumer behaviour and fishing at 3°C GWL:

			– loss of important habitat formers in coastal systems (Brodie et al., 2014) – decrease in PP (Maugendre et al., 2014) above 4°C GWL – 1.5 to 50% losses in macroinvertebrates, larva of economically important species, diversity losses, marine animal biomass, in some regions 70%, shellfish production collapses, loss of habitat of CC species limits their mitigation contribution

Table SM13.27: Transition and confidence levels for the risks of terrestrial ecosystems disruptions due to heat extremes and increase in average temperatures

Risk level	**Range of temperature transitions**	**Confidence level for the transition**	**Explanation (text + references)**
Undetectable to moderate risk	1.0-1.5°C GWL	*Medium*	Increasing evidence across systems but impacts not considered severe and widespread yet based on the evidence. Detected to date (selected from D&A assessment 13.10.1): – Forest growth and production has been impacted by temperature and moisture over the last century (Pretzsch et al., 2014; Seidl et al., 2014; Gazol et al., 2015b; Tian et al., 2016; Alrahahleh et al., 2017; Zlatanov et al., 2017; Marqués et al., 2018; Carnicer et al., 2019a; Ciais et al., 2019; Yuan et al., 2019; Brodribb et al., 2020). – Compound events of heat and drought resulted impacted forest growth with legacy effects into the next year (Schuldt et al., 2020). – Tundra vegetation shrub encroachment accelerated by climate change (Belonovskaya et al., 2016; Martin et al., 2017). – Drought consequences in the Mediterranean region (Fantappié et al., 2011; Stagge et al., 2017; García-Herrera et al., 2019). – Terrestrial species relocation towards higher latitude and altitude have increased in rate (Scherrer and Körner, 2011; Oliver et al., 2015; Melero et al., 2016; Stephens et al., 2016; Wiens, 2016; Bowler et al., 2017; Spooner et al., 2018; Lehikoinen et al., 2019a; van Klink et al., 2020b). – Range shifts altered boreal and alpine tundra (Elmhagen et al., 2015; Post et al., 2019; Mekonnen et al., 2021) and greened polar deserts (Myers-Smith et al., 2020) – Climate-induced biodiversity declines have been detected in thermosensitive groups (Hellmann et al., 2016; Habel et al., 2019; Harris et al., 2019; Crossley et al., 2020; Soroye et al., 2020) including many freshwater plants, molluscs, flying insects, amphibians, reptiles, birds and fishes (Myers et al., 2017; Jarić et al., 2019; Kärcher et al., 2019; Seibold et al., 2019; van Strien et al., 2019; van Klink et al., 2020a).

			– Phenology changes (Hassall et al., 2007; Visser et al., 2012; Karlsson, 2014; Szabó et al., 2016; Thackeray et al., 2016b; Mayor et al., 2017; Asse et al., 2018; Cohen et al., 2018b; Bobretsov et al., 2019 ; Peaucelle et al., 2019; Menzel et al., 2020; Rosbakh et al., 2021) Warming between 1.5 and 2°C is projected to increase the impact including: – Expansion of the subtropical vegetation in SEU (Feyen et al., 2020), large scale threats for forest areas WCEU (Dyderski et al., 2018) – Loss of 50% of the tundra biome in NEU and 40% WCE alpine regions (Feyen et al., 2020) – Loss in peatland area in NEU (Qiu et al., 2020) – Some losses in grassland in WCE (Vermaat et al., 2017) – Extinction risk 5% of species Europe (Urban, 2015) – Loss of 6% of common and 77% of rare freshwater species extinction (Markovic et al., 2014) – 50% of protected area loss of mollusc and freshwater fish (Markovic et al., 2014) – Increasing changes in phenology, creating consumer primary producer mismatch (Thackeray et al., 2016a) – Habitat loss for pollinators in NEU (Rasmont et al., 2015), increasing risk to sensitive pollinators; uncertain net impacts on the service. – Increases in burned area (Wu et al., 2015a) – Increase in soil erosion by 8% in SEU (Berberoglu et al., 2020) increase in rainfall erosivity specially in in NEU (Panagos et al., 2017), increase of soil loss from fire (Pastor et al., 2019b); However, soil erosion is made of many different components (e.g. precipitation, soil type, topography, land use and land management and hence human impacts and vegetation responses to climate change are difficult to separate from climatic effects – Autonomous adaptation allows species to shift ranges, if protected areas are sufficiently large and corridors are available, freshwater bodies are connected, and for plant if soil types and hydrology are appropriate; opportunity for adaptation and reversibility currently which reduces the risk
Moderate to high risk	2.0-2.5°C GWL	*Medium*	The risk is increasing for a larger number of ecosystems and as is the extend of loss and impacts are becoming irreversible: – Increase in wildfire risk in the SEU (Bedia et al., 2014) and increase in burnt area (Camia, 2017), – Expansion of temperate flora 30% NEU, 60% of tundra NEU and 50% of alpine tundra (Feyen et al., 2020), – 50% carbon loss in blanket bogs NEU (Ferretto et al., 2019) – 12% loss of meadows (Wamelink et al., 2020) – Increase in pests such a bark beetle in WCEU (Jakoby et al., 2019b) – Increased extinction risk (Warren et al., 2018) Above 2.5°C GWL: – 70% range contraction in birds in the Alps (Brambilla et al., 2016)

			– Increase in threatened forest area by 46% WCEU (Dyderski et al., 2018) – Up to doubling in burned area (Wu et al., 2015a; Camia, 2017; EEA, 2017b)
High to very high risk	3.3-3.8°C GWL	*High*	The magnitude of several indicators (including losses) are projected to increase very strongly above 3°C GWL: - NEU and SEU tundra nearly completely lost, 70% of alpine tundra (Feyen et al., 2020), - Strong expansion of temperature flora into NEU and subtropical flora into WCEU (Feyen et al., 2020), - Peat turning into carbon source (Qiu et al., 2020) - 8% -16% of species at risk of extinction (Urban, 2015; Warren et al., 2018) Above 3.5 °C GWL: - Large expansion of tree pest species MED, WCEU (Urvois et al., 2021) - 25% Increase in soil erosion SEU (Berberoglu et al., 2020) - Large habitat losses and diversity loss of 10 - 48% of pollinators NEU (Rasmont et al., 2015) - Species risk of extinction 16% (Urban, 2015) - Strong increases of the burned areas in Europe (Wu et al., 2015a; EEA, 2017b) - WCEU threatened forest area 59% (Dyderski et al., 2018)

Table SM13.28: Transition and confidence levels for risk of losses in crop production due to compound heat and dry conditions, and extreme weather (Figure 13.30).

Risk level with low adaptation	**Range of temperature transitions**	**Confidence level for the transition**	**Explanation (text + references)**
Undetectable to moderate risk	0.8-1.1°C GWL	*Medium*	This transition is supported by the D&A assessment in section 13.10.1 and references therein. This transition is placed around the 1°C GWL range. The impacts have been mainly attributed in the case of the extremes, where events in years such as 2010, 2016, 2018 indicate the future on agricultural yields given the expected higher frequency and severity of these events. The average losses across Europe not currently sufficiently large for risk to be widespread. 1.5°C – 1.7°C GWL: – Likelihood of compound events which led to recent large wheat losses are projected to become 12% more frequent, challenging farming systems and yield forecasting systems (Ben-Ari et al., 2018), – Maize yield losses across Europe of 10-25% (Deryng et al., 2014; Webber et al., 2018; Feyen et al., 2020) though strongest in SEU, – Wheat productivity is not impacted at 1.7°C GWL (Webber et al., 2018),

			– Changes in SEU as growing regions shifts northward for melons (Bisbis et al., 2019), tomatoes and grapevines reaching NEU and EEU (Hannah et al., 2013 wine, and conservation; Litskas et al., 2019 a notorious pest and its natural enemy: small scale agriculture at higher risk), – Beginning of abandonment of agricultural land in SEU (Holman et al., 2017), – Warming causes range expansion and alters host pathogen association of pests, diseases and weeds (Caffarra et al., 2012; Pushnya and Shirinyan, 2015; Latchininsky, 2017), – Regionally predicted reduction in rainfall can lead to carryover of herbicides (Karkanis et al., 2018).
Moderate to high risk	2.5-3°C GWL	*Medium*	2°C GWL: – 30% to 50% yield reduction of rainfed maize in SEU (EEA, 2019b; Feyen et al., 2020), – Increase of agricultural droughts (Toreti et al., 2019), – Locally strong changes in yield in arable systems (Diogo et al., 2017), – Increase in toxins in maize in SEU and emergence in WCE (Moretti et al., 2019), – 15% yield loss for sugar beet in rainfed system in SEU (EEA, 2019b). 2.7°C GWL: – Impacts become more widespread as agroclimatic zones move (Ceglar et al., 2019) though there are still regional gains in parts of WCE and NEU (Szewczyk et al., 2018), – Increasing uncertainty on impact on wheat and rapeseed yields in SEU, WCE (Donatelli et al., 2015), – 108% increase in expanse of damaging weed for winter crops (Castellanos-Frias et al., 2016), – Heat stress on wheat EEU (Ceglar et al., 2019), – Negative impact on pollinators results in reduced visits of bees (Nielsen et al., 2017) (see also 13.3.1.3). Between 2.5°C-2.7°C and 3°C GWL, more crops being affected, though there is uncertainty of the extend of potential losses with some gains possible.
High to very high risk	3.8-4°C GWL	*Low*	3°C-4°C GWL: Most of the evidence is focusing below 3°C GWL and above 4°C GWL with limited evidence of impacts between 2.7 and 4 °C GWL. Given that only very small number of papers are available at these warmings, the confidence level is *low*. 3.3°C GWL: – Loss of tomato production in parts of SEU (Bird et al., 2016), – 170% increase in expanse of damaging weed for winter crops (Castellanos-Frias et al., 2016), – NEU becoming a suitable climate for the wheat pest Lolium rigidum (Castellanos-Frias et al., 2016). At 4°C GWL and beyond: – Constant drought conditions similar to the spring/summer 2018 (Ben-Ari et al., 2018),

			– Maize yield losses across Europe of 50-100% (Deryng et al., 2014; Webber et al., 2018; Feyen et al., 2020) – Losses in spring wheat (Deryng et al., 2014) though gains projected for EEU, – Reduction in grassland biomass and start seeing losses in NEU (Jäger et al., 2020), – Increasing losses in agricultural yield SEU and WCE (Szewczyk et al., 2018), – Increased asynchrony between the larvae-resistant growth stages of grapevine and larvae occurrence (Caffarra et al., 2012).
Risk level with high adaptation	**Range of temperature transitions**	**Confidence level for the transition**	**Explanation (text + references)**
Undetectable to moderate risk	0.8-1.1°C GWL	*Medium*	This transition is supported by the D&A assessment in section 13.10.1 and the references therein (Table SM13.1). This transition is placed around the 1°C GWL range. High levels of implementation of multiple adaptation options are assumed for this high adaptation BE. Agricultural production risks can be reduced through irrigation given the availability water resources and suitable infrastructure (Siebert et al., 2017; Ruiz-Ramos et al., 2018; Feyen et al., 2020). The ability to adapt through irrigation is constrained as increasing water is needed to reduce impacts of heat and reduce yield losses with higher temperature and water availability is increasingly limited. Water availability and competing uses is considered in KR3. – Irrigation can reduce projected heat and drought stress, e.g., for wheat and maize (Siebert et al., 2017; Ruiz-Ramos et al., 2018; Feyen et al., 2020) – Irrigation of wheat reverses yield losses across Europe at 2°C GWL to become gains, while yield losses in maize in SEU are reduced from up to 80% to 11% (Feyen et al., 2020). – Changes to cultivars and sowing dates can reduce yield losses, but are insufficient to fully ameliorate losses projected at 3°C warming and above, with an increase of risk from north to south and for crops growing later in the season such as maize (Ruiz-Ramos et al., 2018; Feyen et al., 2020). – Use of longer season varieties can compensate for heat stress on maize in WCE and lead to yield increases for Northern Europe (Siebert et al., 2017; Ceglar et al., 2019) – Moving the growth cycle towards a cooler part of year, reduce the period for photosynthesis and grain filling (Ruiz-Ramos et al., 2018; Holzkämper, 2020), – Physiological constraints such as lack of sufficient light in winter/spring might hinder exploitation of changes in phenology and hence potential for longer growing seasons. – Crop breeding for drought and heat tolerance can improve sustainability of agricultural production under future climate (Costa et al., 2019b), particularly in SEU at 3°C GWL (Senapati et al., 2019), – Multifunctional land use can reduce the dependency on one crop and source of income (Holman et al., 2017),

			– Agricultural water management adaptation such as irrigation, reallocating of water to other crops, improving use efficiency, and soil water conservation practices reduce risks (Iglesias and Garrote, 2015) – In-season forecasts of climate impacts on yield have been used in the 2018 drought for European wheat to inform policy actions (van der Velde et al., 2018). – Greater need for pesticides to control and maintain production, due to range expansion and altered host pathogen association of pests, diseases and weeds affecting health for European crops (Caffarra et al., 2012; Pushnya and Shirinyan, 2015; Latchininsky, 2017) – Simplifying procedures for obtaining subsidies and insurance premiums and interest rates can incentivise adoption of climate friendly agricultural methods (Garrote et al., 2015; Iglesias and Garrote, 2015; Zakharov and Sharipova, 2017; Hamidov et al., 2018; Wiréhn, 2018) Additional evidence from the F&E assessment (Table SM13.5).
Moderate to high risk	Does not reach this threshold	*Medium*	Given high adaption, with the adoption of multiple options, including the availability of sufficient irrigation water and infrastructure, there is little evidence that the risk will reach this level. KR3 considers the availability of water and competing demand, but sufficient water availability required to supply crop irrigation is assumed for the risk level with high adaptation of KR2. See undetectable to moderate risk for evidence above for evidence of adaption options (Table SM13.5)., including irrigation. We concluded that under a high adaptation scenario, the risks do not reach this threshold.
High to very high risk	Does not reach this threshold	-	As per moderate to high risk.

Table SM13.29: Transition and confidence levels for the risks of water scarcity to multiple interconnected sectors (Figure 13.31).

Level of risks due to water scarcity in SEU with low adaptation	**Range of temperature transitions**	**Confidence level for the transition**	**Explanation (text + references)**
Undetectable to moderate risk	0.7-1.1°C GWL	*High*	There is already a moderate risk of water scarcity today (according to D&A; Table 13.13). At 0.6°C, 6 months of drought duration In 1981-2010 (~0.7°C), 48.1m people exposed to moderate water scarcity Literature supporting this transition: (Blauhut et al., 2015; Kebede et al., 2015; Blauhut et al., 2016 ; Gain et al., 2016; Gampe et al., 2016; Stahl et al., 2016; Bisselink et al., 2018; Byers et al., 2018; Naumann et al., 2018; Arnell et al., 2019; Harrison et al., 2019;

			Koutroulis et al., 2019; Bisselink et al., 2020; Cammalleri et al., 2020; Teotónio et al., 2020; Kebede et al., 2021; Naumann et al., 2021)
Moderate to high risk	1.3-1.7°C GWL	*High*	– At 1.5°C, 55.7m of people under moderate water stress (+7.4m) – At 1.8°C, water exploitation index +230% -> transition from moderate to high – At 2°C, doubling of drought duration – At 2°C, 54% of population water stressed – At 2°C, drought duration 10 months Literature supporting this transition: (Kebede et al., 2015; Gampe et al., 2016; Schleussner et al., 2016; Bisselink et al., 2018; Byers et al., 2018; Naumann et al., 2018; Tobin et al., 2018a; Arnell et al., 2019; Harrison et al., 2019; Bisselink et al., 2020; Cammalleri et al., 2020; Feyen et al., 2020; Teotónio et al., 2020; Kebede et al., 2021; Naumann et al., 2021)
High to very high risk	2.5-3.5°C GWL	*Medium*	– At 1.5°C, 55.7m of people under moderate water stress (+7.4m) – at 1.8°C, water exploitation index +230% -> transition from moderate to high – At 2°C, doubling of drought duration – At 2°C, 54% of population water stressed – At 2°C, drought duration 10 months Literature supporting this transition: (Kebede et al., 2015; Gampe et al., 2016; Bisselink et al., 2018; Byers et al., 2018; Naumann et al., 2018; Tobin et al., 2018a; Arnell et al., 2019; Harrison et al., 2019; Koutroulis et al., 2019; Bisselink et al., 2020 ; Cammalleri et al., 2020; Teotónio et al., 2020; Kebede et al., 2021; Naumann et al., 2021)
Level of risks due to water scarcity in SEU with high adaptation	**Range of temperature transitions**	**Confidence level for the transition**	**Explanation (text + references)**
Undetectable to moderate risk	0.9-1.3°C GWL	*Medium*	Improvements in water efficiency and in behaviour are very effective (>25% of damages avoided), in some SSP scenario improvements compared to baseline (Papadimitriou et al., 2019). There is some adaptation deficit now that can be addressed (F&E water assessment, Table SM13.1). Literature supporting this transition:

			(Papadaskalopoulou et al., 2015b; van Vuuren et al., 2015; Greve et al., 2018; Iglesias et al., 2018; Garnier and Holman, 2019; Morote et al., 2019; Papadimitriou et al., 2019) and papers used in the F&E assessment (Table SM.13.1).
Moderate to high risk	1.8-2.2°C GWL	*Medium*	Investment in large water infrastructure and advanced technologies (incl. storage), water transfer, water recycling and reuse, desalinization (Papadaskalopoulou et al., 2015a; Greve et al., 2018) -> buys a bit of time / coping with +0.5°C GWL Literature supporting this transition: (Papadaskalopoulou et al., 2015b; van Vuuren et al., 2015; Greve et al., 2018; Iglesias et al., 2018; Garnier and Holman, 2019; Morote et al., 2019; Papadimitriou et al., 2019) and papers used in the F&E assessment (Table SM.13.1).
High to very high risk	2.8-3.8°C GWL	*Low*	Transformational adaptation is needed, but ultimately there is the risk of planned relocation of industry, development of alternative livelihoods Trade-offs with other adaptation options in need of water (Papadaskalopoulou et al., 2015a; Greve et al., 2018) -> adaptation buys a bit of time / coping with +0.2°C GWL Literature supporting this transition: (Papadaskalopoulou et al., 2015b; van Vuuren et al., 2015; Greve et al., 2018; Iglesias et al., 2018; Garnier and Holman, 2019; Morote et al., 2019; Papadimitriou et al., 2019) and papers used in the F&E assessment (Table SM.13.1).

Level of risks due to water scarcity in WCE with low adaptation	**Range of temperature transitions**	**Confidence level for the transition**	**Explanation (text + references)**
Undetectable to moderate risk	0.6-1.8°C GWL	*Medium*	– At 0.6°C, 5.5-6.8 months of drought duration – At 1.5°C, 6.8-8.3 months of drought duration – In 1981-2010 (~0.7°C), 4.3m people exposed to moderate water scarcity – At 1.5°C, 4.7m of people under moderate water stress (+0.7m) – Number of people exposed is 1 order of magnitude smaller than in SEU (10s of millions) – Note: increase in exposure to moderate, but not severe water scarcity (whereas severe water scarcity in SEU) – Population decline in continental Europe but population increase in France; overall reduces number of people exposed – at 1.8°C, water exploitation index +60% to +200% – There is low risk today (according to D&A)

			Literature supporting this transition: (Blauhut et al., 2015; Kebede et al., 2015; Blauhut et al., 2016; Gain et al., 2016; Schleussner et al., 2016; Stahl et al., 2016; Bisselink et al., 2018; Byers et al., 2018; Naumann et al., 2018; Tobin et al., 2018a; Arnell et al., 2019; Harrison et al., 2019; Koutroulis et al., 2019; Bisselink et al., 2020; Cammalleri et al., 2020; Teotónio et al., 2020; Kebede et al., 2021; Naumann et al., 2021)
Moderate to high risk	2.0-3.0°C GWL	*Medium*	– At 2°C, 16% of population exposed to at least moderate water stress – At 2°C, 7-10 months of drought duration – At 3°C, 8.8-14 months – At 2°C and 2.5°C significant number of people exposed to drought in Continental and Eastern Europe – At 3°C, significant drought losses also in WCE (50% of European GDP losses; particularly in Atlantic region) Literature supporting this transition: (Kebede et al., 2015; Schleussner et al., 2016; Bisselink et al., 2018; Byers et al., 2018; Naumann et al., 2018; Tobin et al., 2018a; Arnell et al., 2019; Harrison et al., 2019; Koutroulis et al., 2019; Bisselink et al., 2020; Cammalleri et al., 2020; Teotónio et al., 2020; Kebede et al., 2021; Naumann et al., 2021)
High to very high risk	4.0-4.5°C GWL	*Low*	– More strongly at 4°C GWL, significant number of people exposed to drought in Continental and Eastern Europe – At 4.5°C GWL, water exploitation index +200% to +310% Literature supporting this transition: (Kebede et al., 2015; Bisselink et al., 2018; Byers et al., 2018; Naumann et al., 2018; Tobin et al., 2018a; Arnell et al., 2019; Harrison et al., 2019; Koutroulis et al., 2019; Bisselink et al., 2020; Cammalleri et al., 2020; Teotónio et al., 2020; Kebede et al., 2021; Naumann et al., 2021)
Level of risks due to water scarcity in WCE with high adaptation	**Range of temperature transitions**	**Confidence level for the transition**	**Explanation (text + references)**
Undetectable to moderate risk	1.5-2.5°C GWL	*Low*	High potential of water efficiency improvements and water savings (>25% of damages avoided), in 50% of scenarios improvements compared to baseline There is some adaptation deficit now, that can be addressed (assumption: +0.5°C GWL) Literature supporting this transition:

			(Collet et al., 2015; van Vuuren et al., 2015; Koopman et al., 2017; Greve et al., 2018; Manouseli et al., 2018; Garnier and Holman, 2019; Papadimitriou et al., 2019) and papers used in the F&E assessment (Table SM.13.1).
Moderate to high risk	3.0-4.0°C GWL	*Low*	Considerable potential for investments in large water infrastructure and advanced technologies (incl. storage), water transfer, water recycling and reuse, desalinization As there is less of such infrastructure in place compared to SEU, there is high potential and effectiveness (assumption: +1°C GWL) Literature supporting this transition: (Collet et al., 2015; van Vuuren et al., 2015; Koopman et al., 2017; Greve et al., 2018; Manouseli et al., 2018; Garnier and Holman, 2019; Papadimitriou et al., 2019) and papers used in the F&E assessment (Table SM.13.1).
High to very high risk	Not reached		

Table SM13.30: Transition and confidence levels for the risks of people, economies and infrastructures due to coastal flooding (Figure 13.32).

Level of risks due to coastal flooding with low adaptation (keeping coastal protection as it is now)	**Range of temperature transitions**	**Confidence level for the transition**	**Explanation (text + references)**
Undetectable to moderate risk	0.8-1.5°C GWL	*Medium*	Based on D&A assessment in Figure 13.29, coastal impacts of climate change are starting to be detected in Europe (see Box 13.1 in Section 13.2); consistent with AR6-SROCC (IPCC, 2019).
Moderate to high risk	1.5-2°C GWL	*Medium*	Expected annual damages projected to rise by a factor of at least 20 for 1.5-2.1°C in EU28 (Vousdoukas et al., 2018); T values bounded by upper scenarios. Consistent with AR5 and AR6-SROCC (IPCC, 2019). Supported by references in Sections 13.2 and 13.6, and consistent with AR5 (Kovats et al., 2014) and AR6-SROCC (IPCC, 2019).
High to very high risk	2-3°C GWL	*Medium*	Expected annual damages projected to rise by two order of magnitude in EU28 above 2 to 3°C of global warming (Vousdoukas et al., 2018; Vousdoukas et al., 2020). Supported by references in sections 13.2 and 13.6. Consistent with AR5 (Kovats et al., 2014) and AR6-SROCC (IPCC, 2019)

Level of risks due to coastal flooding with high adaptation	**Range of temperature transitions**	**Confidence level for the transition**	**Explanation (text + references)**
Undetectable to moderate risk	0.8-1.5°C	*Medium*	Based on D&A assessment in figure 13.29 and F&E assessment (Figure 13.11, Table SM13.1), coastal impacts of climate change are starting to be detected in Europe (see Box 13.1 in Section 13.2); consistent with AR6-SROCC.
Moderate to high risk	1.5-3°C	*Medium*	Expected annual damages projected to rise by a factor of 10 above 2°C and by a factor of 20 above 3°C in EU28 (Vousdoukas et al., 2018; Vousdoukas et al., 2020); Transboundary risks can be limited with high adaptation (Mandel et al., 2021). See also Sections 13.2 and 13.6, Table SM 13.1, and references therein. Consistent with AR5 (Kovats et al., 2014) and AR6-SROCC (IPCC, 2019)
High to very high risk	-	-	Does not reach this threshold

Level of risk from delayed impacts of sea-level rise to cultural heritage and long-living infrastructure	**Range of temperature transition**	**Confidence level for transition**	**Explanation (text & references)**
Undetectable to Moderate	0.5-1.2°C GWL	*Low*	Except in Fennoscandia, European sea levels are projected to rise at rates and magnitudes close to the global average (Fox-Kemper et al., 2021), including Mediterranean sea-levels (CCP4.A.2, CCP4.A.4). Pre-industrial temperatures lead to steady sea-levels (Fox-Kemper et al., 2021), and historical greenhouse gas emissions have committed 0.7 to 1.1m of sea-level rise by 2300 (Fox-Kemper et al., 2021), based on Nauels (2019) Compared to other regions, Europe and particularly South Europe is characterized by a very high number of UNESCO World Heritage sites exposed to sea-level rise (Marzeion and Levermann, 2014; Reimann et al., 2018). This includes Venice, where high-tide flooding has increased consistently with relative sea-level changes (Box 13.1 in Section 13.2).
Moderate to High	1.2-1.5°C GWL	*Low*	Sea levels are projected to rise between 0.3 to 3.1m by 2300 for SSP1-2.6 (*low confidence*) (Fox-Kemper et al., 2021). Sea levels are committed to rise by 2 to 3m after 2,000 years, and by 6 to 7m after 10,000 years for 1.5°C of GWL, but these long term projections incorporate processes in which there is *low confidence* (Fox-Kemper et al., 2021).

			The number of UNESCO World Heritage sites exposed to flooding (erosion) increases with sea-level rise, and so do flood frequencies, intensities, and erosion rates (Reimann et al., 2018).
High to Very High	1.5-2.0°C GWL	*Medium*	Sea-levels are projected to rise between 0.3 to 3.1m by 2300 for SSP1-2.6 (*low confidence*) (Fox-Kemper et al., 2021). Sea-levels are committed to rise by 2 to 6m after 2000 years, and by 8 to 13m after 10,000 years for 2°C of GWL, but these long term projections incorporate processes in which there is *low confidence* (Fox-Kemper et al., 2021). In at least 12 countries in Europe, a stabilization of global warming at about 2°C leads to drowning areas where at least 10% of the population currently live after millennia (Clark et al., 2016).

Table SM13.31: Transition and confidence levels for the risks of people, economies and infrastructures due to inland flooding.

Level of risks due to inland flooding with low adaptation	**Range of temperature transitions**	**Confidence level for the transition**	**Explanation (text + references)**
Undetectable to moderate risk	0.5 – 1.3°C GWL	*High*	Same references as for Figure 13.29 (Table SM13.22). Additional evidence from the trends in the hazards (pluvial floods) (Ranasinghe et al., 2021; Seneviratne et al., 2021) and based on independent expert assessment of the literature of two LAs and additional support of 2 CAs. The upper value for this transition is 1.3°GWL because it is within the likely range for observed global warming from pre-industrial, (see AR6 WGI Cross-Chapter Box 2.3) and to distinguish from the impacts at 1.5°GWL which have been assessed to be well within the moderate risk level. Namely, LAs considered the potential for severe consequences to happen sooner than later (before reaching 1.5°C) given the persistence of certain conditions in the hazards (see WGI) and exposure (high population density along river banks and urban infrastructures difficult to change), for example 22% of present flood damage losses arise in Europe (second after Asia) between 1976-2005 (Dottori et al., 2018); 8-26 billion Euro of economic losses; affected population: 156-679 10^3 pp/year (Alfieri et al., 2018); at 1°C GWL, population exposed to 100-year return discharge increases by 3%-30% in some grid cells in WCE and NEU (Lange et al., 2020). However, there is also evidence that vulnerability is decreasing for example: increase in annually inundated area and number of people affected since 1870 but no significant trend in normalized financial losses 1970-2006; substantial decline in fatalities since 1950; contrast between Northern and Southern Europe;

			increased hazard but decreased vulnerability of population and assets (Paprotny et al., 2018).
Moderate to high risk	1.5°C-2.5°C GWL	*Medium*	Based on quantitative flood hazard projections (Ranasinghe et al., 2021), flood risk projections (Ciscar et al., 2014; Jongman et al., 2014; Alfieri et al., 2017; Ciscar et al., 2018; Arnell et al., 2019; Harrison et al., 2019; Dottori et al., 2020; Hosseinzadehtalaei et al., 2020; Lange et al., 2020; Merz et al., 2021 impacts and patterns of disastrous river floods), considering potential for cascading risks as part of the criteria for key risk severity (Chapter 16) and considering that limited adaptation put human lives at risk from flooding.
High to very high risk	2.5-3°C GWL	*Medium*	Based on projections suggesting flood hazard and risks continue to increase above 3° GWL (Alfieri et al., 2017; Hosseinzadehtalaei et al., 2020) (Sections 13.2 and 13.6), and considering limited ability of current systems to protect and accommodate flooding. At 3°C GWL evidence suggests that the magnitudes of severe consequences increase considerably, and such consequences are also more widespread for both economic damage and people affected. Therefore, very high risks are plausible beyond 3°GWL. For example, at 3°C GWL, around 600-700 bi in damage in Western Central Europe compared to approx. 100 bi in the baseline. We also observe about quadrupling in part of Russia (Merz et al., 2021 impacts and patterns of disastrous river floods). Furthermore, under SSP5 welfare losses (compared to SSP5 baseline without climate change): Western Europe -0.17%; Russia: -0.52; but: indirect losses are increasing more strongly than direct losses between 1.5°C and 3°C because of the persistence of the damages in the economy (Dottori et al., 2018). For Europe in total, there is a slight increase in the population exposed; the difference between 1.5°C and 3°C GWL is small and not significant (Dottori et al., 2018). At 4°C GWL, 87% increase in pluvial flood risks (Hosseinzadehtalaei et al., 2020). There is *medium confidence* though given that evidence finds population exposed to riverine flooding to increase strongly in NEU (up to 300%); as well as in central and western parts of WCE, but to decrease in eastern parts of WCE; there is also a slight increase in SEU.

Level of risks due to inland flooding with high adaptation	**Range of temperature transitions**	**Confidence level for the transition**	**Explanation (text + references)**
Undetectable to moderate risk	0.5-1.5°C GWL	*Medium*	Same references as for Figure 13.6 (Table SM13.1); Additional evidence from the trends in the hazards (pluvial floods) (Ranasinghe et al., 2021; Seneviratne et al., 2021). The higher transition reflects higher adaptation potential, e.g. 1.5°C GWL (RCP 2.6 SSP1/SSP4), population exposed to coastal and riverine flooding decreases by >25% in Alpine, Northern, Continental, Southern and increases or stays constant in Atlantic (Papadimitriou et al., 2019). Up to around 1.6°C GWL increasing flood protection levels in all basins to a minimum of 1 per 100 years would decrease the total expected annual flood losses by 30% (Jongman et al., 2014) 1.6 (A1B-2050), if insurance penetration increases from 30% to 50%, uninsured losses would drop by 60% (Jongman et al., 2014).
Moderate to high risk	2.5-3°C GWL	*Medium*	Based on quantitative flood risk projections for SSP5 (Alfieri et al., 2017; Arnell et al., 2019; Harrison et al., 2019), considering that flood damage in Europe could be compensated by adaptation (Jongman et al., 2014; Alfieri et al., 2016a; Dottori et al., 2020), but also that city drainage systems are difficult to upgrade and empirical evidence that city adaptation remains slow today (Ürge-Vorsatz et al., 2018). Under 3°C GWL same number of people exposed but 12% reduction in damage (river flood) (Dottori et al., 2020) (using building scale measures). If we approximate high adaptation with SSP1 conditions, at 4°C GWL, 14-23% less increase in pluvial flood risks under RCP4.5-SSP1 compared to RCP8.5-SSP5 (where the increases is 87%) (Hosseinzadehtalaei et al., 2020). However, the residual risk is still considerable. Furthermore, there is persistency of hazard and exposure conditions as well as limitations in drainage systems (see (Dale et al., 2018; Dale, 2021). Additional evidence from the F&E assessment (Table SM13.1).
High to very high risk	-	-	Does not reach this threshold

SM13.11 Supplementary Material Supporting the Development of Adaptation Pathways

This section describes the approach used to derive the illustrative adaptation pathways underpinning Figures 13.31-13.34. Adaptation pathways are established in scientific literature on climate adaptation planning to support decision making under deep uncertainty and break adaptation into manageable steps over time. Adaptation pathways map possible sequencing of adaptation options (or portfolio of options or strategies) as a function of global warming (global surface air temperature) and/or time. The basis for deriving adaptation pathways in AR6 WGII Chapter 13 is following the methods described in Haasnoot (2013) and Haasnoot (2019). The adaptation pathways built on the results of the burning embers developed for the key risks (Section 13.10.2), selection of adaptation options and the assessment of their feasibility and effectiveness in Sections 13.2.2, 13.5.2, 13.6.2 and 13.7.2.

Methodology for deriving the illustrative pathways in Chapter 13

Step 1: Decide on the scope and narratives of the adaptation pathways

In step 1, the author team developed the pathway narrative based on the key risk aggregation (13.10.2) and the aggregation of the options in the feasibility and effectiveness (F&E) assessments described in Table SM13.1, Table SM13.5, Table SM13.15, Table SM13.19. Through discussions, the teams decided on the type of illustrative pathways for the different key risks, for example for each of the European regions (SEU; NEU; WCE) or hazard type (e.g. coastal and riverine flood). Based on the burning embers and the F&E assessments, suitable combinations of measures and their sequencing were agreed and translated into narratives supporting the pathways. Only measures with at least *medium confidence* were considered. Each statement has full traceability to the F&E assessment tables in the Supplementary Materials.

Step 2: Construct the pathways

The available information on effectiveness to reduce risk per GWL or time was used when available. In absence of such information, evidence was used from adaptation options already implemented that have demonstrated medium to high effectiveness in reducing risk. Based on the inventory of adaptation options, the relative effectiveness (e.g. A is better than B in reducing risk) was determined.

Path-dependencies were identified during discussions with the team (e.g. if option A is implemented then option B is not possible, difficult to implement, or not logical). Storylines and narratives were used to describe the implementation of adaptation options over time (e.g., first option A, then option B, and if risk increases further, then C or D is a long-term option). Changes in GWLs affecting these options, the path-dependency of options, and feasibility of implementation were considered. Pathways typically started with low-regret options that allowed adding of more adaptation options and reducing risk under different levels of warming.

Statements developed in step 1 were aggregated to facilitate graphic visualisation, and to be presented in the text. Confidence levels were assigned to the statements. Several intermediate versions of the pathways were drafted, and discussed with the author team until consensus was reached. When the effectiveness of measures was dependent on the region or the hazard, different pathways maps were designed, for example for Key Risk 1 (heat and human health). All pathways are visually presented using the following logic:

- measures belonging to a similar strategy (e.g. protect or resist) or similar type of measures (e.g. engineering measures) are presented close to each other in the figure.
- current situation is indicated in the centre
- adaptation measures that reduce risk only at low GWLs (thus low effectiveness) are shown close to the present situation, and options with higher effectiveness at higher GWLs are either on the top or bottom of the figure. As such pathways typically start in the centre of the pathways map (close to the present) and move towards the outer corners.
- when two or more measures are needed to reduce the risk, their respective lines are joined together.

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