

Supplement:



Table S1. The interlinkage of cryosphere services with SDG targets

The interlinkage between 15 SDGs (excluding SDG16 and 17, see explanations in the paper) and 62 targets establish with 12 services is developed, expressed by direct/indirect and strong/weak categories. More specifically , the dark red, light red, dark green and light green correspond to the category of direct-strong, direct-weak, indirect-strong, and indirect-weak interlinkage between CS and SDG targets, respectively.

Table S2. The Eigenvector centrality of SDG targets in five communities of the developed network

SDG targets	Eigenvector centrality	Main cryosphere service
2.4	0.629	
6.6	0.695	
10.7	0.378	
12.2	0.598	Runoff regulation
12.3	0.216	Climate regulation
14.5	0.387	Hydrothermal regulation
15.1	0.778	Habitation
15.2	0.611	
15.3	0.647	
15.4	0.626	
15.5	0.557	
1.1	0.773	
1.2	0.781	
1.5	0.740	
2.1	0.480	
2.3	0.510	Freshwater
3.9	0.348	Clean energy
6.1	0.573	Infrastructure/engineering
6.5	0.282	
7.1	0.533	
8.5	0.287	
11.1	0.673	
11.2	0.442	
11.5	0.726	
13.1	0.855	
2.a	0.205	
3.d	0.196	
7.3	0.384	
8.4	0.703	Research/education
9.4	0.284	
9.5	0.177	
12.a	0.168	
8.1	0.524	Religious/spirit/culture
10.1	0.337	Aesthetic/recreation
11.4	0.445	Snow/ice material
6.3	0.201	
6.4	0.208	Environment regulation
14.1	0.196	

Table S3. The classification of the targets related to CS with the six entry points

Entry points	Main aspects in GSDR 2019	Targets (keywords)
Human well-being and capabilities	Life expectancy, material wellbeing and health, education and quality of life, equality opportunities, eliminate deprivations and build resilience,	1.1 (eradicate extreme poverty)
		1.2 (reduce poverty)
		1.5 (build the resilience of the poor)
		11.5 (reduce the number of deaths)
		10.1 (income growth of the bottom)
		6.1 (access to drinking water)
		8.5 (employment and decent work)
		1.4 (resources distribution)
		3.d (the capacity for the health risks)
		13.3 (education and capacity)
		5.1 (end all forms of discrimination)
		4.7 (acquire the knowledge and skills)
		12.8 (sustainable development information, awareness)
		5.a (equal rights to resources)
		8.1 (per capita economic growth)
Sustainable and just economies	Gross domestic product, environmental externality costs, net output, equality of production and consumption	12.2 (efficient use of natural resources)
		11.5 (decrease the direct economic losses)
		8.4 (economic growth from environmental degradation)
		9.4 (resource-use efficiency)
		6.4 (increase water-use efficiency)
		12.a (scientific and technological capacity)
		8.9 (promote sustainable tourism that creates jobs)
		12.4 (management of chemicals and all wastes)
		14.c (sustainable use of oceans and their resources)
		12.b (sustainable tourism that creates jobs)
Food systems and nutrition patterns	Sustainable agricultural production, soil health, greenhouse gas emissions from agriculture, safe nutrition for all	8.5 (full and productive employment)
		2.1 (end hunger)
		2.4 (sustainable food production systems)
		2.3 (the agricultural productivity and incomes)
		12.3 (reduce food waste and losses)
		6.4 (increase water-use efficiency)
		2.a (agricultural productive capacity)
		2.5 (genetic diversity of seeds)
Energy decarbonization and universal access	Effective supply of energy, decarbonization of energy, reduction of greenhouse gas emission	7.1 (affordable, reliable and modern energy services)
		7.3 (increase the energy efficiency)
		7.b (sustainable energy services for all)
		7.2 (increase the share of renewable energy)
		7.a (clean energy research and technology)

Urban and peri-urban development	Social management and protection, Equality, Decent work, enhance research and technology, policy, infrastructure of transport systems, buildings, etc.	1.5 (build the resilience of the poor)
		13.1 (resilience and adaptive capacity in all countries)
		11.5 (protecting the poor in vulnerable situations)
		11.1 (housing and basic services and upgrade slums)
		10.7 (planned and well-managed migration policies)
		11.2 (improving road safety, expanding public transport)
		6.5 (integrated water resources management)
		6.4 (increase water-use efficiency across all sectors)
		9.1 (regional and transborder infrastructure)
		1.4 (resources distribution)
		7.b (expand infrastructure and upgrade technology)
		9.4 (upgrade infrastructure for and retrofit industries)
		11.4 (protect the cultural and natural heritage)
		11.b (integrated policies and plans)
		11.c (building sustainable and resilient buildings)
		9.5 (the technological capabilities of industrial sectors)
		1.a (implement programmes and policies to end poverty)
		15.1 (terrestrial and inland freshwater ecosystems)
		15.3 (desertification and land degradation)
Global environmental commons	Biodiversity conservation, Nature resources, Environment friendly and treatment (air, land, and ocean), Climate change	6.6 (water-related ecosystems)
		15.4 (mountain ecosystems)
		15.2 (sustainable management of forests)
		15.5 (natural habitats and threatened species)
		11.5 (protect people in vulnerable situations)
		14.5 (coastal and marine areas)
		14.1 (reduce marine pollution of all kinds)
		14.2 (marine and coastal ecosystems)
		14.3 (ocean acidification)
		13.2 (Integrate climate change measures)
		3.9 (pollution and contamination)
		6.3 (reducing pollution, eliminating dumping)
		9.4 (clean and environmentally sound technologies)
		14.c (Convention on the Law of the Sea)
		11.6 (environmental impact, air quality, etc)
		15.9 (integrate ecosystem and biodiversity values)

Note: The six entry points are not a single pathway but contain multiple dimensions to the implements of SDGs and targets. The pathways in association with basic human needs, economy, agriculture, energy, society and environment to achieve transformational change towards sustainable development through the six entry points.

The 2019 Global Sustainability Report (GSDR 2019) provides a detailed overview of the dimensions of the six entry points and the main aspects involved as shown in the supplement of Table S3. The 17 Sustainable Development Goals (SDGs) are comprehensive goals, and 169 targets correspond to all aspects of the SDGs. 62 targets related to cryosphere services divide into six categories: human needs, economy, agriculture, energy, society and ecology dimensions corresponding to the SEPs in the supplementary table S3.

Table S4. The eigenvector centralities of targets in six entry point networks

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Table S5. Direct and indirect casual effects of the cryosphere service on SDG targets, developed on the basis of references

SDG Targets	Cryosphere Services	Causal Effects	References
Goal 1. End poverty in all its forms everywhere			
Target 1.1 By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than \$1.25 a day	Fresh water	Meltwater→economic system (agriculture, husbandry and other industries)→increase income to eradicate extreme poverty	(Sherpa et al., 2014; Viviroli et al., 2020)
	Clean energy	Electric energy→economic(social) system→promote economic growth and eradicate multidimensional poverty	(Gaudard et al., 2016; Vergara et al., 2007)
	Runoff regulation	Runoff regulation→seasonal water allocation (agricultural irrigation)→ensure sustainable food production to eradicate extreme poverty	(Nüsser and Baghel, 2016)
	Climate regulation	Climate regulation→reduce the frequency of climate change hazards→eradicate extreme poverty caused by the climate change	(Hallegatte et al., 2015; Reyer et al., 2017)
	Hydrothermal regulation	Ecological regulation (hydrothermal)→maintain the stability of ecosystem services→eradicate extreme poverty caused by natural disaster (i.e. frost)	(Smadja et al., 2015)
	Aesthetic & Recreational	Aesthetic & Recreational→the development of cryosphere tourism→increase income to eradicate extreme poverty	(Blair, 2015; Wang et al., 2010)
	Habitation	Habitation→provide a stable environment for agricultural and livelihood→reduce losses and eradicate extreme poverty	(Prasain, 2018; Yang et al., 2018; Young et al., 2018)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (transportation, pipeline, etc)→promote economic development and eradicate poverty	(Johnston, 1982; Yershov, 1998)
Target 1.2 By 2030, reduce at least by half the proportion of men, women and children of all ages living in poverty in all	Fresh water	Meltwater→sustainable food production systems (agricultural, husbandry, etc)→eradicate multidimensional poverty	(Sherpa et al., 2014; Viviroli et al., 2020)
	Clean energy	Electric energy→economic(social) system→promote economic growth and eradicate multidimensional poverty	(Gaudard et al., 2016; Vergara et al., 2007)

its dimensions according to national definitions	Runoff regulation	Runoff regulation→seasonal water allocation (agricultural irrigation)→ensure sustainable food production to eradicate extreme poverty	(Nüsser and Baghel, 2016)
	Climate regulation	Climate regulation→reduce the frequency of climate change hazards→eradicate dimension poverty caused by the climate change	(Hallegate et al., 2015)
	Hydrothermal regulation	Ecological regulation (hydrothermal)→maintain the stability of ecosystem services→eradicate extreme poverty caused by ecological environment changes	(Smadja et al., 2015)
	Aesthetic & Recreational	Aesthetic & Recreational→the development of cryosphere tourism→increase income to eradicate extreme poverty	(Blair, 2015; Wang et al., 2010)
	Habitation	Habitation→provide a stable environment for livelihood and reduce the impacts of cryosphere changes→reduce losses and multidimensional poverty	(Bury et al., 2013)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (road, railway, etc)→promote economic development and eradicate extreme poverty	(Johnston, 1982; Yershov, 1998)
Target 1.4 By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance	Fresh water	Meltwater→ensure the economic resources and access to basic services	(Sherpa et al., 2014; Viroli et al., 2020)
	Clean energy	Electric energy→ensure the economic resources and access to basic services	(Gaudard et al., 2016; Vergara et al., 2007)
	Hydrothermal regulation	Ecological regulation (hydrothermal)→maintain the stability of ecosystem services→provide economic resources to access to basic services	(Qin et al., 2020; Smadja et al., 2015)
	Runoff regulation	Runoff regulation→spatial and temporal scale allocation of water resources→have equal rights to basic services and equitable distribution	(Nüsser and Baghel, 2016; Vuille et al., 2018)
Target 1.5 By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and	Fresh water	Meltwater→access to safe and affordable water for agriculture→reduce the exposure to climate change hazards (drought, etc.)	(Dangi et al., 2018; Huss et al., 2017)
	Climate regulation	Climate regulation→reduce the frequency to exposure to climate change hazards	(Rasmussen, 2016)

vulnerability to climate change hazards and other economic, social and environmental shocks and disasters	Runoff regulation	Runoff regulation→seasonal water allocation (agricultural irrigation)→build the resilience to reduce the exposure to climate change hazards	(Vuille et al., 2018)
	Research & Education	Research & Education (environment awareness and measurement)→build the resilience to reduce the exposure to climate change hazards	(Nüsser et al., 2018)
	Habitation	Habitation→provide a stable environment for livelihood→build the resilience to reduce the exposure to climate change hazards	(Parveen et al., 2015)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (building, transports, etc)→build the resilience and reduce the exposure to climate hazards	(Johnston, 1982; Yershov, 1998)
Target 1.a Ensure significant mobilization of resources from a variety of sources to implement programmes and policies to end poverty in all its dimensions	Fresh water	Meltwater→ensure mobilization of resources from a variety of sources	(Sherpa et al., 2014)
	Clean energy	Electric energy→ensure mobilization of resources from a variety of sources	(Gaudard et al., 2016; Vergara et al., 2007)

Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Target 2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round	Fresh water	Meltwater→agricultural irrigation→protect agricultural output and sufficient food to end hunger	(Biemans et al., 2019; Nüsser and Schmidt, 2017; Qin et al., 2020)
	Climate regulation	Climate regulation→reduce the frequency of climate change hazards (pests, hazards, diseases, etc)→protect agricultural output to end hunger	(FAO, 2018; Najafi et al., 2019; Myers et al., 2017)
	Hydrothermal regulation	Ecological regulation (hydrothermal)→maintain the stability of agro-ecosystem→protect agricultural output and sufficient food to end hunger	(Mukherji et al., 2019)
	Runoff regulation	Runoff regulation→seasonal water resource for agricultural irrigation→ensure sustainable food production to end hunger	(Nüsser and Baghel 2016; Qin et al., 2020)
Target 2.3 By 2030, double the agricultural productivity and incomes of small-scale	Habitation	Habitation→provide a stable environment for agricultural system→protect agricultural output and sufficient food to end hunger	(Gentle and Maraseni, 2012; Ingti, 2017; Qin et al., 2020)
	Fresh water	Meltwater→agricultural irrigation→increase agricultural productivity and output	(Biemans et al., 2019; Nüsser and Schmidt, 2017)

food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment	Climate regulation	Climate regulation→reduce the frequency of climate change hazards (pests, hazards, diseases, etc) →protect agricultural output, productivity and incomes	(FAO, 2018; Viviroli et al., 2020)
	Runoff regulation	Runoff regulation→seasonal water resource for agricultural irrigation→ensure sustainable food production systems	(Barnett et al., 2005; Nüsser and Baghel, 2016; Qin et al., 2020)
	Habitation	Habitation→provide a stable environment for agricultural system→protect agricultural output and increasing agricultural productivity	(Gentle and Maraseni, 2012; Ingty, 2017; Qin et al., 2020)
Target 2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality	Fresh water	Meltwater→protect the agricultural output→ensure sustainable food production systems	(Biemans et al., 2019; Nüsser and Schmidt, 2017; Pritchard, 2019)
	Climate regulation	Climate regulation→reduce the frequency of climate change hazards (pests, hazards, diseases, etc) →ensure sustainable food production systems	(FAO, 2018; Myers et al., 2017)
	Runoff regulation	Runoff regulation→seasonal distribution of water resources for agricultural irrigation→ensure sustainable food production systems	(Nüsser et al., 2018; Nüsser and Baghel 2016)
	Hydrothermal regulation	Ecological regulation (hydrothermal)→maintain the stability of agro-ecosystem→ensure sustainable food production systems	(Mukherji et al., 2019)
	Research & Education	Research & Education (cryosphere serves agriculture practices)→establish a stable agricultural system	(Fuhrer et al, 2014; Hussain et al., 2018)
	Infra & Engineering	Permafrost engineering supporting→rural infrastructure construction (building, irrigation, etc)→ensure sustainable food production and to end hunger	(Johnstone, 1981; Yershov, 1998)
Target 2.5 By 2020, maintain the genetic diversity of seeds through diversified seed and plant banks at the national, regional and international levels	Habitation	Habitation→provide a stable environment for agricultural system→ensure sustainable food production systems	(Bury et al., 2011; Gentle and Maraseni, 2012; Ingty, 2017)
	Habitation	Habitation→provide a stable environment for ecosystem→maintain the genetic diversity of seeds	(SROCC, 2019)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (seed banks)→maintain the genetic diversity	(Chin, 1994)

Target 2.a Increase investment in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries	Research & Education	Research & Education (cryosphere serves agriculture practices)→strengthen agricultural research and establish a stainable agricultural system	(Nusser et al., 2019; Nüsser and Baghel, 2016)
	Infra & Engineering	Permafrost engineering supporting→rural infrastructure construction (building, irrigation, etc)→enhance agricultural productive capacity	(Johnstone, 1981; Yershov, 1998)

Goal 3. Ensure healthy lives and promote well-being for all at all ages

Target 3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination	Environmental regulation	Environmental regulation (contaminents storage)→reduce the number of deaths and illnesses from pollution and contamination	(Colombo et al., 2018; Hodson, 2014; Milner et al., 2017; Søndergaard et al., 2015)
	Climate regulation	Climate regulation→reduce the frequency of climate-related disasters and the number of deaths and illnesses from hazardous	(Estallo et al., 2015; Li and Yap, 2011; Sherpa, 2014)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (waste storage)→reduce the number of deaths and illnesses from hazardous chemicals	(Glotov et al., 2018; Govaerts et al., 2016)
	Research & Education	Research & Education→improve awareness and measures to the cryosphere-derived contaminants→reduce the number of deaths and illnesses from contamination	(Colombo et al., 2018)
Target 3.d Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks	Environmental regulation	Environmental regulation (contaminents storage)→reduce the number of deaths and illnesses from pollution and contamination	(Colombo et al., 2018; Milner et al., 2017)
	Research & Education	Research & Education (cryosphere changes and impact)→improve risk awareness and emergency measures→strengthen capacity for adaptation to climate change	(Fuhrer et al., 2014; Hussain et al., 2018; Rasul et al., 2019)
	Climate regulation	Climate regulation→reduce the frequency of climate-related disasters→strengthen capacity for adaptation and risk reduction to climate change	(Rasmussen, 2016; Sherpa, 2014)

	Infra & Engineering	Permafrost engineering supporting → infrastructure construction → strengthen the capacity to cope with disasters risks	(Duvillard, 2019; Phillips and Margreth, 2008)
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Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

Target 4.7 By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education, lifestyles and of culture's contribution to sustainable development	Climate regulation	Climate regulation → reduce the frequency of climate-related disasters → reduce the influence of climate change to the education of the population	(Kara and Yucel, 2015)
	Research & Education	Research & Education → acquire the knowledge and skills needed to promote cryosphere sustainable development	(IPCC, 2018; SROCC, 2019)
	Religious & Spirit & Cultural	Religious & Spirit & Cultural → lifestyles and of culture's (knowledge and skills) contribution to sustainable development	(Brugger et al., 2013; Gagne et al., 2014)
Target 4.a Build and upgrade education facilities that are child, disability and gender sensitive and provide safe, non-violent, inclusive and effective learning environments for all	Climate regulation	Climate regulation → reduce the frequency of climate-related disasters → provide safe learning environments for all	(Kara and Yucel, 2015; Sherpa et al., 2014)
	Infra & Engineering	Permafrost engineering supporting → infrastructure construction (build and upgrade school and related education facilities)	(Vincent et al., 2013)

Goal 5. Achieve gender equality and empower all women and girls

Target 5.1 End all forms of discrimination against all women and girls everywhere	Climate regulation	Climate regulation → reduce the frequency of climate-related disasters to the poverty → end all forms of discrimination against for all	(Verma and Khadka, 2011)
	Religious & Spirit & Cultural	Religious spirit and cultural services → universal spiritual value for all → end all forms of discrimination	(UNESCO, 2012)
	Infra & Engineering	Permafrost engineering supporting → infrastructure construction → providing economic development and disaster-resistant for all	(Vincent et al., 2013)
Target 5.a Undertake reforms to give women equal rights to economic resources,	Fresh water	Meltwater → access to water resources for all → ensure equal rights to economic water resources	(Dangi et al., 2018; Huss et al., 2017)

as well as access to ownership and control over land and other forms of property, financial services, inheritance and natural resources, in accordance with national laws	Clean energy	Electric energy→access to affordable, reliable and modern energy for all→ensure equal rights to hydropower resources Realize the popularization of electric energy	(IHA, 2018, 2020; McDowell et al., 2013)
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Goal 6. Ensure availability and sustainable management of water and sanitation for all

Target 6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all	Fresh water	Meltwater→access to safe and affordable drinking water for all	(Beniston and Stoffel, 2014; Dangi et al., 2018; Huss et al., 2017)
	Runoff regulation	Runoff regulation→seasonal distribution of water resources to ensure access to affordable water for all	(Buytaert and Bievre, 2012)
	Environmental regulation	Environmental regulation (contaminants concentration)→reduce contaminants (organic, inorganic, etc) and access to safe water for all	(Milner et al., 2017; Rui et al., 2014; Zaharescu et al., 2016)
	Habitation	Habitation→provide a stable environment for water-related ecosystem→access to water for all	(Beniston and Stoffel, 2014; Gentle and Thwaites, 2016)
Target 6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	Environmental regulation	Environmental regulation (contaminants storage)→reduce contaminantsin and improve water quality	(Milner et al., 2017)
	Research & Education	Research & Education (cryosphere contaminants concentration)→risk awareness and implementation measures→improve water quality by reduce pollution	(Glotov et al., 2018)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (waste storage)→improve water quality by reduce pollution	(Glotov et al., 2018; Govaerts et al., 2016)
Target 6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water	Freshwater	Meltwater→ensure sustainable withdrawals and supply of freshwater to address water scarcity	(Dangi et al., 2018; Huss et al., 2017)
	Runoff regulation	Runoff regulation→seasonal distribution of the water to increase water-use efficiency	(Farinotti et al., 2019; Nüsser et al., 2019)

scarcity and substantially reduce the number of people suffering from water scarcity	Research & Education	Research & Education→cryosphere meltwater utilization and distribution→substantially increase water-use efficiency to address water scarcity	(Orlove et al., 2019; Rasul and Molden, 2019)
Target 6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	Freshwater	Meltwater→water resources supply→implement integrated water resources management	(Jamir, 2016; Yang et al., 2014)
	Runoff regulation	Runoff regulation→seasonal distribution of the water resources for social-economic system→implement integrated water resources management	(Xenarios et al., 2019)
	Climate regulation	Climate regulation→mitigate the impact of climate change on water supply and demand→implement integrated water resources management	(Gaudard et al., 2014)
	Hydrothermal regulation	Ecological regulation (hydrothermal)→spatial-temporal distribution of ecology water resources→implement integrated water resources management	(Zhang et al., 2020)
	Research & Education	Research & Education (meltwater research)→risk awareness and responses strategies→implement integrated water resources management	(Archer et al., 2010; Barnett et al., 2005; Giacomelli et al., 2008)
Target 6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	Fresh water	Meltwater (ecology water)→protect and restore water-related ecosystems	(Milner et al., 2017; Schoen et al., 2017)
	Runoff regulation	Runoff regulation→seasonal allocation of ecological water and nutrients→protect and restore water-related ecosystems	(Fell et al., 2017, 2018; Hawkings et al., 2014; Lawson et al., 2014)
	Hydrothermal regulation	Ecological regulation (hydrothermal)→protect and restore water-related ecosystems	(Comola et al., 2015; Matteodo et al., 2016)
	Climate regulation	Climate regulation→mitigate the impact of climate change and protect water-related ecosystems	(Hoegh-Guldberg et al., 2018; Milner et al., 2017)
	Research & Education	Research & Education→environment awareness to protect the water-related ecosystems	(Rosvold, 2016)
	Aesthetic & Recreational	Aesthetic & Recreational→environment awareness and sustainable development→protect and restore water-related ecosystems	(Garavaglia et al., 2012; Garavaglia and Pelfini, 2011)
	Religious & Spirit & Cultural	Cryosphere religious and cultural→environment awareness and protect cryosphere meltwater-related ecosystems	(Allison, 2015; Hussain et al., 2018)

	Habitation	Habitation→provide a stable environment to protect and restore water-related ecosystems	(Eby et al., 2014; Fell et al., 2017, 2018; Vuille et al., 2018)
Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all			
Target 7.1 By 2030, ensure universal access to affordable, reliable and modern energy services	Clean energy	Electric energy→access to affordable, reliable and modern energy	(Chen et al., 2005; Farinotti et al., 2019; IHA, 2018, 2020; McDowell et al., 2013)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (dam. etc)→the foundation of hydropower to access to clean energy	(Schwanghart et al., 2016)
Target 7.2 By 2030, increase substantially the share of renewable energy in the global energy mix	Clean energy	Electric energy→increase renewable energy and substantially the share of renewable energy	(Farinotti et al., 2019; IHA, 2018, 2020; IRENA, 2018; McDowell et al., 2013)
	Research & Education	Research & Education (hydropower related cryosphere)→environmental awareness and technology to increase the renewable energy	(Farinotti et al., 2019; Hamudududu and Killingveit, 2012)
Target 7.3 By 2030, double the global rate of improvement in energy efficiency	Clean energy	Electric energy→double the rate of improvement in efficiency of clean energy production	(Farinotti et al., 2019; IHA, 2018, 2020)
	Research & Education	Research & Education (hydropower related cryosphere)→incorporate strategies into management →increase renewable energy production efficiency	(Braun and Fournier, 2016; Farinotti et al., 2019)
Target 7.a By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in	Research & Education	Research & Education (hydropower related cryosphere)→environmental awareness and actions→increase substantially of the renewable energy	(Braun and Fournier, 2016; Farinotti et al., 2019)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (dam. etc)→the foundation of hydropower to access to clean energy	(Schwanghart et al., 2016)

energy infrastructure and clean energy technology			
Target 7.b By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, in accordance with their respective programmes of support	Clean energy	Electric energy→supply modern and sustainable energy services	(Chen et al., 2005; Farinotti et al., 2019; IHA, 2018, 2020; McDowell et al., 2013)
	Infra & Engineering	Permafrost engineering supporting→expand infrastructure construction (dam, etc) for supplying modern and sustainable energy services	(Schwanghart et al., 2016)
	Research & Education	Research & Education (hydropower related cryosphere)→hydropower engineering technology for supplying energy services	(Karki et al, 2015; Terrier et al., 2015)

Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Target 8.1 Sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7 percent gross domestic product growth per annum in the least developed countries	Fresh water	Meltwater→economic system (agriculture, husbandry and other industries)→economic growth in accordance with national circumstances	(Milner et al., 2017; Schoen et al., 2017; Sherpa et al., 2014; Sturm et al., 2017)
	Clean energy	Electric energy→economic benefits of electricity energy→economic growth in accordance with national circumstances	(Gaudard et al., 2016; Vergara et al., 2007)
	Ice & Snow materials	Cryosphere resources (Ice & Snow conditions)→basis of cryosphere tourism→economic growth in accordance with national circumstances	(Grünwald et al, 2015; Paden et al., 2013; Steiger et al., 2019; Vanat, 2018, 2020)
	Climate regulation	Climate regulation→reduce the frequency of climate change hazards→ensure the economic stability and growth	(Beaudin and Huang, 2014; Prowse, 2009; Scott, 2019; Spandre et al., 2019a, 2019b)
	Runoff regulation	Runoff regulation→seasonal distribution of the water resources for agriculture→economic growth	(Bokhorst et al., 2016; Nüsser et al., 2018)

	Hydrothermal regulation	Ecological regulation (hydrothermal)→protect and restore eco-tourism→sustain economic growth	(Council, Arctic, 2013)
	Aesthetic & Recreational	Aesthetic & Recreational→cryosphere tourism development to improve the economic growth in accordance with national circumstances	(Konchar et al., 2015; Vanat, 2018, 2020; Wang et al., 2010)
	Religious & Spirit & Cultural	Religious & Spirit & Cultural→cryosphere tourism development to improve the economic growth in accordance with national circumstances	(Becken et al., 2013)
	Research & Education	Research & Education (cryosphere serves economic research)→utilization and distribution of cryosphere resources→sustainable economic research	(Spandre et al., 2019a, 2019b; Steiger et al., 2017)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction→increasing the economic development	(Johnstone, 1983; Yershov, 1998)
Target 8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-Year Framework of Programmes on Sustainable Consumption and Production, with developed countries taking the lead	Clean energy	Electric energy→access to affordable, reliable and modern energy for economic→economic growth from environmental degradation	(Hamududu and Killingtveit, 2012; IHA, 2018, 2020)
	Runoff regulation	Runoff regulation→seasonal distribution of the water resources to increase the water use efficiency	(Nusser et al., 2019)
	Research & Education	Research & Education→utilization and management of cryosphere resources→improve economic growth from environmental degradation	(Orlove et al., 2019; Rasul and Molden, 2019)
Target 8.5 By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value	Aesthetic & Recreational	Aesthetic & Recreational→the development of cryosphere tourism→achieve full and productive employment and decent work	(Blair, 2015; Konchar et al., 2015; Wang et al., 2010)
	Religious & Spirit & Cultural	Religious & Spirit & Cultural→the development of cryosphere tourism→achieve full and productive employment and decent work	(Becken et al., 2013)

Target 8.9 By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products	Aesthetic & Recreational	Aesthetic appreciation and winter sports→promote sustainable cryosphere tourism→creates jobs and promotes local culture and products	(Sherpa et al., 2014; Spandre et al., 2019a, 2019b; Wang et al., 2010)
	Religious & Spirit & Cultural	Religious & Spirit & Cultural→cryosphere tourism development→creates jobs and promotes local culture and products	(Becken et al., 2013)
	Research & Education	Research & Education→incorporating knowledge about cryosphere tourism to devise and implement policies→promote sustainable tourism	(Cuerrier et al., 2015)

Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Target 9.1 Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all	Research & Education	Research & Education→enhance scientific research and technological capabilities of permafrost engineering→develop quality, reliable, sustainable and resilient infrastructure in frozen ground regime	(Auld et al., 2006; Cheng, 2005a, 2005b; Ma et al., 2009; Shi et al., 2012; Wang et al., 2020)
	Infra & Engineering	Permafrost engineering supporting→quality, reliable, sustainable and resilient infrastructure	(Chai et al., 2018; Guo and Wang, 2016; Lai et al., 2012; Xu et al., 2010; Yu et al., 2016)
Target 9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (upgrade and sustainable retrofit infrastructure)	(Chai et al., 2018; Guo and Wang, 2016; Lai et al., 2012; Xu et al., 2010)
	Research & Education	Research & Education→enhance scientific research and technological capabilities of permafrost engineering→upgrade infrastructure in frozen ground regime	(Bommer et al., 2010; Dore et al., 2016; Ma et al., 2009; Shi et al., 2012; Xu et al., 2010)

Target 9.5 Enhance scientific research, upgrade the technological capabilities of industrial sectors	Research & Education	Research & Education (cryosphere research)→enhance scientific research and technological capabilities of permafrost engineering	(Gardner and Dekens, 2006; Ma et al., 2009; Shi et al., 2012; Wang et al., 2020)
Goal 10. Reduce inequality within and among countries			
Target 10.1 By 2030, progressively achieve and sustain income growth of the bottom 40 percent of the population at a rate higher than the national average	Fresh water	Meltwater→economic system (agriculture, husbandry and other industries)→achieve and sustain income growth of low-income people	(Sherpa, 2014; Viviroli et al., 2020)
	Clean energy	Electric energy (hydropower)→social economic system (economic and energy sectors)→provide employment opportunities for low-income people and increase their income	(Gaudard et al., 2016)
	Ice & Snow materials	Cryosphere resources→basis of cryosphere tourism→increase the income growth of low-income people	(Blair, 2015; Wobus et al., 2017)
	Climate regulation	Climate regulation→reduce the frequency of climate change hazards→ensure the economic stability→increasing the income growth	(FAO, 2018; Najafi et al., 2019)
	Runoff regulation	Runoff regulation→seasonal water allocation (agricultural irrigation)→progressively achieve and sustain income growth	(Nüsser and Baghel, 2016)
	Aesthetic & Recreational	Aesthetic & Recreational→cryosphere tourism development→create employment and income opportunities for the poor	(Denning, 2014; Vanat, 2018, 2020)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (transportation, pipeline, etc)→economic development and increasing the income growth	(Johnstone, 1981; Yang et al., 2019)
Target 10.7 Facilitate orderly, safe, regular and responsible migration and mobility of people, including through the	Habitation	Habitation→provide a stable environment for economic→progressively achieve and sustain income growth	(CAFF, 2013)
	Fresh water	Meltwater→basic services for the livelihood (agriculture, husbandry, etc)→migration and mobility caused by meltwater	(Nyima and Hopping, 2019; Prasain, 2018)
	Climate regulation	Climate regulation→reduce the frequency of climate change hazards→reduce passive migration caused by climate-related disaster	(FAO, 2018; Najafi et al., 2019)

implementation of planned and well-managed migration policies	Runoff regulation	Runoff regulation→seasonal water allocation (agricultural irrigation, etc)→reduce passive migration caused by insufficient meltwater	(Barnett et al., 2005; Rasul and Molden, 2019)
	Hydrothermal regulation	Ecological regulation (hydrothermal regulation)→protect the agriculture and husbandry system→reduce passive migration caused by ecological disaster	(Gentle and Thwaites, 2016; Ingty, 2017)
	Research & Education	Research & Education (cryosphere livelihoods)→impact assessment and coping strategies→facilitate orderly, safe, regular and responsible migration	(SROCC, 2019)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (building, transportation, etc)→strengthen capacity to avoid passive migration caused by disaster	(Duvillard et al., 2019; Phillips and Margreth, 2008)
	Habitation	Habitation→provide a stable cryosphere environment for livelihood→avoid passive migration caused by climate-related disaster	(Merrey et al., 2018; Mukherji et al., 2019)

Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable

Target 11.1 By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums	Fresh water	Meltwater resources→ensure access for all to adequate, safe and affordable freshwater	(Buytaert et al., 2017; Drenkhan et al., 2019)
	Clean energy	Electric energy→ensure access for all to adequate, safe and affordable clean energy	(Hamududu and Killingtveit, 2012; IHA, 2018, 2020)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (adequate, safe and affordable housing) for all in frozen ground	(Vincent et al., 2013)
	Climate regulation	Climate regulation→reduce the frequency of climate-related diasaters→access to adequate, safe basic services	(Barnett et al., 2005)
	Habitation	Habitation→provide a stable environment for ecology and livelihood→ensure access to basic services	(Jurt et al., 2015)
Target 11.2 By 2030, provide access to safe, affordable, accessible and sustainable	Research & Education	Research & Education→enhance technological capabilities of permafrost engineering→develop quality, reliable, sustainable and resilient infrastructure in frozen ground regime	(Cheng, 2005a, 2005b; Ma et al., 2009; Shi et al., 2012)
	Research & Education	Research & Education (permafrost engineering)→risk management and engineering technology→access to safe and sustainable transport systems	(Larsen et al., 2008; Shi et al., 2012; Wang et al., 2020)

transport systems for all, improving road safety, notably by expanding public transport	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (road, railway, etc) for the sustainable transport systems	(Chai et al., 2018; Shi et al., 2012; Vincent et al., 2013)
Target 11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage	Fresh water	Meltwater→protect and restore the ecosystems→protect and safeguard the culture and natural heritage related ecosystems	(McNeeley, 2017)
	Ice & Snow materials	Cryosphere resources (natural heritage carrier)→protect and safeguard the cryosphere cultural and natural heritage	(Bosson et al., 2019; Konchar et al., 2015)
	Climate regulation	Climate regulation→reduce climate change and related impact to protect the natural heritage	(Rhoades et al., 2008)
	Hydrothermal regulation	Ecological regulation (hydrothermal regulation)→protect and safeguard the natural heritage	(Urban et al., 2014; Woo and Young, 2014)
	Research & Education	Research & Education (cryosphere cultural values)→environment awareness to protect and safeguard the natural heritage	(Bosson et al., 2019; SROCC, 2019)
	Religious & Spirit & Cultural	Cryosphere religious and cultural→strengthen efforts to protect and safeguard the world's cultural and natural heritage	(Bosson et al., 2019; Callanan, 2016; UNESCO, 2012)
	Aesthetic & Recreational	Aesthetic & recreational (climate change tourism)→envrionment awareness to protect and safeguard the world's cultural and natural heritage	(Garavaglia, 2012; Garavaglia and Pelfini, 2011)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction→protect and safeguard the cultural and natural heritage	(Chai et al., 2018; Vincent et al., 2013)
Target 11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to	Habitation	Habitation→provide a stable environment for socio-ecosystemt (carrier of the spiritual and intrinsic)→protect cryosphere cultural and natural heritage	(Oliversmith, 1979; Tschakert et al., 2019)
	Fresh water	Meltwater resources→mitigating disasters caused by water shortage→decrease the economic losses caused by water-related disasters	(Gentle and Thwaites, 2016)
	Climate regulation	Climate regulation→decrease the economic losses and the number of deaths affect by climate change hazards	(FAO, 2018)

global gross domestic product caused by disasters, with a focus on protecting the poor and people in vulnerable situations	Runoff regulation	Runoff regulation→seasonal water allocation for economic system→decrease the economic losses caused by water-related disasters	(Wrathall et al., 2014)
	Research & Education	Research & Education (permafrost engineering)→building sustainable and resilient buildings→reduce the affect and economic losses caused by disasters	(Doré et al., 2016)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction→improve the ability to resist disasters and reduce economic losses	(Walker and Peirce, 2015)
	Habitation	Habitation→provide a stable environment for livelihood→reduce immigration and the economic losses	(IHCAP, 2017; Nothiger and Elsasser, 2004)
Target 11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	Environmental regulation	Environmental regulation→reduce environmental contaminants (organic, inorganic, etc) impact of cities	(Bogdal et al., 2010; Hodson, 2014)
	Research & Education	Research & Education (cryosphere environment)→environmental awareness and actions→reduce the adverse environment impact of cities	(Milner et al., 2017)
Target 11.b By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans to climate change, resilience to disasters, and develop and implement, holistic disaster risk management at all levels	Research & Education	Research & Education (permafrost engineering)→improve the engineering to respond to cryosphere changes→increase the resilience apacity to disasters	(Dore et al., 2016; Hill et al., 2017)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (building, road, dam, etc) to increase the sustainable cities and settlements to climate change	(Walker and Peirce, 2015)
Target 11.c Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials	Infra & Engineering	Permafrost engineering supporting→support for sustainable and resilient buildings	(Duvillard et al., 2019; Phillips and Margreth, 2008)
	Research & Education	Research & Education (permafrost engineering)→improve the engineering technical→technical assistance to build the sustainable buildings	(Bommer et al., 2010; Doré et al., 2016)

Goal 12. Ensure sustainable consumption and production patterns

Target 12.2 By 2030, achieve the sustainable management and efficient use of natural resources	Fresh water	Meltwater resources→achieve the sustainable use of natural resources in economic system (agriculture, husbandry and tourism)	(Barnett et al., 2005; Becken et al., 2013)
	Clean energy	Hydropower→achieve the sustainable management and efficient use of cryosphere natural resources	(Hamududu and Killingtveit, 2012; IHA, 2018, 2020)
	Ice & Snow materials	Ice & Snow materials→achieve the sustainable management and efficient use of natural resources for cryosphere tourism	(Blair, 2015; Hagenstad et al., 2018; Vanat, 2018, 2020)
	Climate regulation	Climate regulation→maintain the stability of the cryosphere resources→improve the sustainable management and efficient use of natural resources	(Hoegh-Guldberg et al., 2018; Scott et al., 2018; Steiger et al., 2017)
	Runoff regulation	Runoff regulation→seasonal allocation of water resources to achieve the sustainable use of water resources	(Braun and Fournier, 2016)
	Research & Education	Research & Education→sustainable management and efficient use of cryosphere resources	(Scott et al., 2015)
	Aesthetic & Recreational	Aesthetic & Recreational→cryosphere tourism development→achieve the sustainable management and efficient use of cryosphere resources	(Denning, 2014; Hagenstad et al., 2018; Vanat, 2018, 2020)
	Religious & Spirit & Cultural	Cryosphere religious and cultural→cultural heritage value and development utilization→achieve the sustainable management and efficient use of natural resources	(Serdeczny, 2019; UNFCCC, 2014)
Target 12.3 By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses	Infra & Engineering	Permafrost engineering supporting→infrastructure construction→ensure sustainable management and efficient use of natural resources	(Guo and Wang, 2016; Yu et al., 2016)
	Fresh water	Meltwater→agricultural irrigation→reduce the frequency of water-related hazards→reduce food losses along production	(Barrett and Bosak, 2018; Biemans et al., 2019; Nüsser and Schmidt, 2017; Rasul and Molden, 2019)
	Climate regulation	Climate regulation→reduce the frequency of climate change hazards and pests and diseases→reduce food losses along production	(FAO, 2018)

	Runoff regulation	Runoff regulation→seasonal water allocation for irrigation→ensure sustainable food production systems,reduce food losses along production	(Nüsser et al., 2019; Nüsser and Baghel 2016)
	Hydrothermal regulation	Ecological regulation (hydrothermal)→stable agricultural ecological system→protect agricultural output and reduce food losses along production	(Qin et al., 2020; Smadja et al., 2015)
Target 12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment	Environmental regulation	Environmental regulation (contaminents reserve)→reduce contaminants release to environment and minimize the impacts on health	(Douglas et al., 2012; Zaharescu et al., 2016)
	Research & Education	Research & Education→cryosphere contaminants circulate and enrich→minimize the impacts on health and environment	(Langford et al., 2010)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction (wastes storage)→minimize the impacts on health and environment	(Yang et al., 2007)
Target 12.8 By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature	Research & Education	Research & Education→improve the awareness of sustainable development and lifestyles in harmony with nature	(IPCC, 2014c, 2019; SROCC, 2019)
	Aesthetic & Recreational	Aesthetic & Recreational→cryosphere tourism sustainable development in harmony with nature	(Stewart et al., 2016; Wang et al., 2010)
	Religious & Spirit & Cultural	Cryosphere religious and cultural→awareness for sustainable development and lifestyles in harmony with nature	(Serdeczny, 2019; UNFCCC, 2014)
Target 12.a Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production	Research & Education	Research & Education (cryosphere sustainable development)→strengthen the scientific and technological capacity to the sustainable development	(IPCC, 2014a, 2014b; IPCC, 2018; SROCC, 2019)
Target 12.b Develop and implement tools to monitor sustainable development	Ice & Snow materials	Ice & Snow materials (cryosphere tourism resources)→creates jobs and promotes local sustainable tourism	(Vanat, 2018, 2020)

impacts for sustainable tourism that creates jobs and promotes local culture and products	Religious & Spirit & Cultural	Cryosphere religious and cultural services→promotes sustainable tourism and creates jobs	(Xiao et al., 2019)
	Aesthetic & Recreational	Aesthetic appreciation and recreational services (climate change tourism)→creates jobs and promotes sustainable tourism	(Stewart et al., 2016; Wang et al., 2010)

Goal 13. Take urgent action to combat climate change and its impacts

Target 13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries	Fresh water	Meltwater for social ecological and economic systems→strengthen resilience and adaptive capacity to the drought disaster	(Pritchard, 2019; Wu et al., 2015)
	Runoff regulation	Runoff regulation→seasonal allocation of water resources to strengthen the capacity to the climate-related disaster	(Hussain et al., 2018; Huss and Hock, 2018)
	Climate regulation	Climate regulation→mitigate global warming and climate-related hazards and natural disasters in all countries	(Matthes et al., 2015; Mu et al., 2017)
	Hydrothermal regulation	Ecological regulation (hydrothermal regulation)→mitigating the impact of climate change on ecology	(Yang et al., 2018; Zhang et al., 2011)
	Research & Education	Research & Education→risk awareness of cryosphere changes and impact→strengthen capacity to climate-related hazards	(SWIPA, 2017; SROCC, 2019)
	Infra & Engineering	Permafrost engineering supporting→infrastructure construction(dam, etc) to strengthen capacity to climate-related hazards and natural disasters	(Duvillard et al., 2019; Phillips and Margreth, 2008)
Target 13.2 Integrate climate change measures into national policies, strategies and planning	Habitation	Habitation→provide a stable environment for livelihood→strengthen resilience and adaptive capacity to climate-related hazards and natural disasters	(Rasmussen, 2016)
	Climate regulation	Climate regulation→mitigate global warming and climate-related disasters→integrate into national policies, strategies and planning	(SROCC, 2019)
	Research & Education	Research & Education (cryosphere changes and impact)→strengthen awareness and capacity→integrate measures into policies, strategies and planning	(IPCC, 2014, 2019; Lepage and Dore, 2010)
	Religious & Spirit & Cultural	Cryosphere religious and cultural→cryosphere culture resources protection→integrate measure into national policies, strategies and planning	(Schirpke et al., 2016)

Target 13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning	Climate regulation	Climate regulation→mitigate global warming and climate-related disasters→improve capacity on climate change mitigation, adaptation, impact reduction	(Rasmussen, 2016)
	Research & Education	Research & Education (cryosphere changes and impact)→improve education, awareness-raising and human and institutional capacity on climate change	(IPCC, 2014, 2019; Lepage and Dore, 2010; SWIPA, 2017)
	Religious & Spirit & Cultural	Religious & Spirit & Cultural (indigenous/local knowledge tied to religious beliefs)→improve education, awareness-raising on climate change	(Brugger et al., 2013; Mark et al., 2010)

Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Target 14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from landbased activities, including marine debris and nutrient pollution	Runoff regulation	Runoff regulation→regulate the meltwater and contaminants into ocean→prevent and significantly reduce marine pollution	(AMAP, 2017; Peterson et al., 2002)
	Climate regulation	Climate regulation→mitigate global warming and climate-related impacts→reducing the impact on marine and coastal ecosystems	(Gobler, 2020; Wassmann, 2011)
	Environmental regulation	Environmental regulation (concentrate and circulate)→regulate contaminant to the marine and coastal ecosystems	(Douglas et al., 2012; Sun et al., 2017, 2018)
	Research & Education	Research & Education (cryosphere nutrients, contaminants concentrate and circulate)→protect the environment and reduce pollution from rivers	(Ask et al., 2009; Rautio et al., 2011)
Target 14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans	Runoff regulation	Runoff regulation→regulate the meltwater and related material into ocean→protect marine and coastal ecosystems to avoid significant adverse impacts	(AMAP, 2017; Greene et al., 2008; Michael, 2021)
	Climate regulation	Climate regulation→mitigate global warming and significant climate-related impacts→sustainably manage and protect marine and coastal ecosystems	(Wassmann, 2011)
	Research & Education	Research & Education→the concentration and circulation of cryosphere nutrients, contaminants to the marine→protect marine and coastal ecosystems	(Hawkings et al., 2016; SROCC, 2019)
Target 14.3 Minimize and address the impacts of ocean acidification, including	Runoff regulation	Runoff regulation→regulate the meltwater and organic carbon into ocean→conserve coastal and marine areas	(Spencer et al., 2009)

through enhanced scientific cooperation at all levels	Climate regulation	Climate regulation→mitigate global warming and the meltwater into the arctic marine→minimize the impacts of ocean acidification	(Oschlies, 2021; Peterson et al., 2002)
	Research & Education	Research & Education→(cryosphere changes affect ocean acidification)→awareness,strategies and methods to minimize the ocean acidification	(SROCC, 2019; SWIPA, 2017)
Target 14.5 By 2020, conserve at least 10 percent of coastal and marine areas, consistent with national and international law and based on the best available scientific information	Runoff regulation	Runoff regulation→regulate the meltwater and nutrient into ocean→conserve coastal and marine areas	(AMAP, 2017; Peterson et al., 2002)
	Climate regulation	Climate regulation→mitigate global warming and climate-related disasters→conserve coastal and marine areas	(Wassmann, 2011)
	Research & Education	Research & Education→the impact of the cryosphere changes to marine system→conserve coastal and marine areas	(Hawkings et al., 2016; SROCC, 2019)
Target 14.c Enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in the United Nations Convention on the Law of the Sea	Climate regulation	Climate regulation→mitigate global warming and climate-related disasters→enhance the conservation and sustainable use of oceans	(Wassmann, 2011)
	Research & Education	Research & Education→the awareness of marine environment with cryosphere change→enhance the conservation and sustainable use of oceans	(Ask et al., 2009; Rautio et al., 2011)

Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Target 15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements	Fresh water	Meltwater→ensure the conservation, restoration and sustainable use of freshwater ecosystems and services	(Hawkings et al., 2014; Stuefer and Kane, 2016)
	Runoff regulation	Runoff regulation→seasonal allocation of ecological water to ensure the sustainable of freshwater ecosystems and services	(Giersch et al, 2015, 2017; Hawkings et al., 2014; Lawson et al., 2014)
	Climate regulation	Climate regulation (radiative forcing)→ensure the conservation, restoration and sustainable use of ecosystems and services	(Hoegh-Guldberg, 2018; Milner et al., 2017)
	Hydrothermal regulation	Ecological regulation (hydrothermal regulation)→ensure the sustainable use of ecosystems and services	(Urban et al., 2014; Woo and Young, 2014; Zhao et al., 2018)

	Research & Education	Research & Education→cryosphere changes and impact to ecosystems→ensure the conservation and sustainable use of ecosystems and services	(Rosvold, 2016)
	Aesthetic & Recreational	Aesthetic & recreational (climate change tourism)→envrionment awareness and protection→ensure the sustainable use of freshwater and terrestrial ecosystems	(Garavaglia et al., 2012; Garavaglia and Pelfini, 2011)
	Religious & Spirit & Cultural	Cryosphere religious and cultural→protect freshwater ecosystems related culture→ensure the sustainable of freshwater ecosystems and services	(Allison 2015)
	Habitation	Habitation→provide a stable environment for freshwater ecosystems→ensure the sustainable of freshwater ecosystems and their services	(Cooper, 2014; Giersch et al., 2017; Milner et al., 2017)
Target 15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally	Fresh water	Meltwater→promote the implementation of sustainable management of forests and their services	(Jamir, 2016; Yang et al., 2014)
	Runoff regulation	Runoff regulation→seasonal allocation of ecological water to ensure the sustainable of freshwater ecosystems and services	(Sun et al., 2016)
	Climate regulation	Climate regulation→ensure the conservation, restoration and sustainable use of freshwater ecosystems and services	(Dobrowski and Parks, 2016)
	Hydrothermal regulation	Ecological regulation (hydrothermal)→promote the implementation of sustainable management of forests and their services	(Shen et al., 2018; Wang et al., 2017; Zhang et al., 2020)
	Research & Education	Research & Education→cryosphere changes and impact to ecosystems→promote the implementation of sustainable management of forests	(Jones et al., 2018; Mills et al., 2018)
	Religious & Spirit & Cultural	Cryosphere religious and cultural→protect mountain culture→ensure the sustainable of freshwater ecosystems and services	(Rosvold, 2016)
	Habitation	Habitation→provide a stable environment to prevent forests ecosystem	(Gentili et al., 2015; Panetta et al., 2018; Rosvold, 2016)
Target 15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and	Fresh water	Meltwater (ecosystem water)→combat desertification, restore degraded land and soil	(Pritchard, 2019; Woo and Young, 2014)
	Runoff regulation	Runoff regulation (seasonal allocation of ecological water)→mitigate the seasonal drought of the land affected by desertification and drought diseaster	(Woo and Young, 2014)

strive to achieve a land degradation-neutral world	Climate regulation	Climate regulation→mitigate ecological changes to combat desertification, restore degraded land and soil	(Gao et al., 2015; Zhang et al., 2011)
	Hydrothermal regulation	Ecological regulation (hydrothermal)→prevent the land ecosystem to avoid the degradation (ground thermal regime)	(Blok et al., 2015; Dhakar and Pandey, 2020; Harpold and Molotch, 2015; Leffler and Welker, 2013)
	Religious & Spirit & Cultural	Cryosphere religious and cultural→protect culture related mountain cryosphere→protects land system to avoid the degradation	(Allison 2015)
	Research & Education	Research & Education→cryosphere changes and impact to ecosystems→protect the soil properties and minimize the land degradation	(Leffler, 2016; Zhou, 2013a, 2013b)
	Habitation	Habitation→provide a stable environment to prevent the desertification, restore degraded land and soil (i.e. ground thermal regime, soil organic carbon)	(Paudel, 2010)
Target 15.4 By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development	Fresh water	Meltwater (ecosystems water resource)→ensure the conservation of mountain ecosystems	(Luus et al., 2013; Pritchard, 2019)
	Runoff regulation	Runoff regulation→seasonal allocation of ecological water to conserve mountain ecosystems	(Sun et al., 2016)
	Climate regulation	Climate regulation→mitigate global warming and climate-driven disaster→ensure the conservation of mountain ecosystems	(Brugger et al., 2013; Serreze and Barry 2011)
	Hydrothermal regulation	Hydrothermal regulation (high albedo, low thermal conductivity)→ensure the conservation of mountain ecosystems (ground thermal regime)	(Kissel et al., 2019; Semenchuk et al., 2013; Zhao et al., 2018)
	Research & Education	Research & Education→cryosphere changes and impact to ecosystems→effects and strategies to conserve mountain ecosystems	(Rasul et al., 2019; SROCC, 2019)
	Aesthetic & Recreational	Aesthetic & recreational (climate change tourism)→environment awareness→ensure the conservation of mountain ecosystems	(Garavaglia et al., 2012; Garavaglia and Pelfini, 2011)
	Religious & Spirit & Cultural	Cryosphere religious and cultural→protect the nature resources→ensure the conservation of mountain ecosystems	(Allison 2015)

	Habitation	Habitation→provide a stable natural habitats→ensure the conservation and sustainable development of mountain ecosystems	(Gentili et al., 2015; IHCAP, 2017)
Target 15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species	Fresh water	Meltwater(soil moisture,habitats)→reduce the degradation of natural habitats and biodiversity	(Luus et al., 2013)
	Runoff regulation	Runoff regulation→seasonal allocation of ecological water→reduce the degradation of natural habitats and biodiversity	(Sun et al., 2016; Wilhelm et al., 2013)
	Climate regulation	Climate regulation→maintain the ecological habitat and reduce the degradation of natural habitats and biodiversity	(Wheeler et al., 2015, 2016)
	Hydrothermal regulation	Ecological regulation (hydrothermal effect, season length)→reduce the degradation of natural habitats and biodiversity (i.e. soil temperature, environmental changes)	(Semenchuk et al., 2019; Zhang et al., 2021)
	Research & Education	Research & Education→cryosphere changes and impact to ecosystems (i.e. soil temperatures)→take action to reduce the degradation of natural habitats and biodiversity	(Bjorkman et al., 2015; Goncharova et al., 2019; Zhang et al., 2021)
	Aesthetic & Recreational	Aesthetic & recreational (climate change tourism)→envrionment awareness→take action to reduce the degradation of natural habitats	(Garavaglia et al., 2012; Garavaglia and Pelfini, 2011)
	Religious & Spirit & Cultural	Cryosphere religious and cultural→protection of the nature resources→reduce the degradation of natural habitats and biodiversity	(Allison, 2015; Gagne et al., 2014)
	Habitation	Habitation (cold conditions, stable environment)→protect natural habitats and reduce the degradation of biodiversity	(Dhakar and Pandey, 2020; Fauteux et al., 2015; Ingty, 2017; White et al., 2018; Wilhelm et al., 2013)
Target 15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts	Research & Education	Research & Education→cryosphere services value research→integrate cryosphere services values into national and local planning	(Wang et al., 2019; Xiao et al., 2016, 2019)
	Religious & Spirit & Cultural	Cryosphere religious and cultural→awareness to protect the nature resources→integrate cryosphere services values into planning	(Allison, 2015)

Table S5 references for SDGs linked to the cryosphere service

Goal 1. End poverty in all its forms everywhere

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Goal 5. Achieve gender equality and empower all women and girls

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