Economic Value of Ecosystem Services, Minerals and Oil in a Melting Arctic: a Preliminary Assessment

<u>**Supplementary Material**</u>

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This document outlines the data sources, procedures and assumptions used to obtain estimates of the economic value of key Arctic ecosystem goods and services. Caveats and limitations are briefly touched on at the end. All values are presented in 2016 US$. Where necessary, economic values have been adjusted to account for inflation, and other currencies adjusted to account for income differences, using the World Bank's purchasing power parity conversion factors. Populations statistics have been obtained from various sources; these are listed below (Section 12) under 'Sources of Data for Population Statistics'.

1. Food (subsistence)

Subsistence harvest data was only available for Alaska, collected for the Alaska Division of Fish and Game (ADF&G) Subsistence Survey and published online at the Community Subsistence Information System (CSIS) website[1]. This dataset consists of (mostly) annual subsistence harvest data for the year 2012 for various locations across Alaska, including 'Arctic Alaska', which consists of the rural communities of Golovin, Kotzebue, Noorvik and Point Lay (CSIS, 2012). Urban communities are also included in this dataset, of which only Prudhoe Bay is above the Arctic Circle. Hence, subsistence harvest values for this community are also included. Although non-indigenous people also hunt, these are a minority and generally fall under "domestic harvest" category. It will be assumed that the subsistence harvest accrues only to indigenous Arctic communities, and that amounts extracted have remained constant over the past four years.

To extrapolate the subsistence harvest values for Alaska to the rest of the Arctic, the average amount harvested per capita was used (this includes fish, land mammals, marine mammals,

[1] Available at http://www.adfg.alaska.gov/sb/CSIS/

birds, shellfish and plants) and assumed the same per capita harvest for all adult Arctic indigenous people in 2016. However, given the great difference in per capita harvest of rural Arctic communities (average 438lb/capita/year) versus urban communities (22lb/capita/year), I have assumed 25% of the Arctic indigenous population (approx. 400,000 people in total, based on data from 2004) live in rural areas and 75% live in urban areas, based on figures in Bogoyavlenskiy and Siggner (2004). In order to estimate economic values, I have used a replacement cost of between \$4 - \$8/lb, as suggested in Fall (2014) obtaining thus a range of values.

Table S1: Food (subsistence) values (2016 US$)

Rural versus urban	Annual wild food harvest (lb per capita)	Number of people	Annual gross value (2016 US$ bn)	Annual net value (2016 US$ bn)
Rural indigenous communities in Arctic	438	100,000	0.27 (0.19 – 0.37)	0.22 (0.15 – 0.29)
Urban indigenous communities in Arctic	22	300,000	0.04 (0.03 – 0.05)	0.03 (0.02 – 0.04)
All indigenous communities		400,000	0.31 (0.21 – 0.42)	0.25 (0.17 – 0.33)

Ideally, the total value of subsistence harvests presented in this study would be net of costs associated with engaging in harvest activities (the correct value of subsistence harvest). However, to the best of my knowledge there are no estimates of the costs of subsistence harvest to Arctic communities. Therefore, I assume average harvest costs to be 20% of the benefits of subsistence harvest following Costanza et al. (1997), although they apply this to subsistence harvests from forests which are very different from Arctic tundra and ice. However, in the absence of more precise estimates, this will be used albeit with caution.

2. Food (fisheries, commercial)

Valuation of commercial fisheries uses secondary data reported in Vilhjálmsson and Hoel (2013). The authors source the fisheries production and revenue data from the various Directorates of fisheries of the Arctic fishing nations (Canada, Greenland, Iceland, USA (Alaska), Norway and Russia). Because we are interested in the economic value of ecosystem goods and services rather than their market value, the costs of production must be subtracted from total revenue. To do this, I have assumed average costs of production to be 80% of revenue, based on figures in the World Bank's *Sunken Billions* report (Arnason et al., 2008).

3. Table S2: Food (fisheries, commercial) values (2016 US$)

Region	Fishing nation	Annual revenue (2016 US$ billions)	Annual value (2016 US$ billions)
Northeast Atlantic – Barents and Norwegian Seas	Norway	2.79	0.56
Central North Atlantic – Iceland and Greenland	Iceland & Greenland	1.70	0.34
Newfoundland and Labrador Seas, Northeastern Canada	Canada	0.62	0.12
North Pacific – Bering Sea	Alaska (economic data for Russian not available)	1.22	0.24
All Arctic fishing regions	All	6.33	1.26

4. Minerals

Mining data was obtained from Haley et al. (2011), who sourced Arctic mineral production data from a wide range of sources, including statistical, geological and mining organisations. Their review covers historical production from 1980 until 2007 (except for oil and gas) for Alaska, Canada, Greenland, Svaalbard, Sweden, Finland and Norway (no available data for Russia). However, they note that:

‘Data for mining in the Arctic have been irregular and inconsistent either because of its proprietary nature, different reporting standards, or their inclusion into greater numbers for the country at large. Mining’s contribution to Arctic economies therefore remains unclear.’ (p38).

For the present study, I use average production value from 2004-2007 to minimise the influence of rapidly increasing production in frontier regions (Alaska, Canada, Greenland) which took place mostly between 1998-2004. From 2004-2007, production levels are fairly stable in frontier regions. Notably, mature mining regions (Sweden, Finland, Norway) have relatively stable production at around $2bn overall between 1992 and 2007. Due to huge fluctuations in the price of minerals, Haley et al. (2011) estimate average production values at long term average US price (1980-2007), by mineral, in billions of dollars.

Given a dearth of robust data on production costs of mining, and a very large variation in what available data there is, I have assumed that 50% of mining revenue comprises costs (based on average production costs for hard rock mining in Alaska reported in Rothe, 2006).

5. Oil

Data on oil production was obtained from the U.S. Energy Information Administration website for the year 2012. There are 19 oil basins in the Arctic region, but significant oil production is only taking place on the North Slope (Alaska) and in the Northwest Arctic region of Russia (including Komi Republic, Arkhangelsk and Yakutiya). Although the Komi Republic oil fields are just below the Arctic circle (at around 64 degrees), they produce oil from the Timan-Pechora oil basin which overlies the Arctic Circle, extending across 61°-72° north latitude and 44°-66° east longitude (Lindquist, 1999). Rather than assign an arbitrary fraction of oil production from the Komi oil fields to the Arctic region, I have opted to include all production from this oil field in this analysis. Annual oil production figures are based on 2012 data rather than a mean over 5 or 10 years because production in the North Slope is rapidly declining per year.

We estimate the average price per barrel as the average price over the year 2016, which comes to $104.92. The cost of oil extraction was calculated by assuming that the Arctic has the same costs for producing crude oil and natural gas. Furthermore, this number may not sufficiently describe the particular case of the Arctic and the special exploration and extraction costs connected to such a frozen environment. Using the average of off-shore and on-shore drilling in America including both lifting and finding costs under Total Upstream Costs (Source: US EIA, 2010)

Table S3: Costs for Producing Crude Oil and Natural Gas, 2007-2009 ($2009 on a per barrel of oil equivalent)

United States	Lifting Costs	Finding Costs	Total Upstream Costs
On-shore	$12.73	$18.65	$31.38
Off-shore	$10.09	$41.51	$51.60
Average	$12.18	$21.58	$33.76

Source: US EIA, 2010

Adjusted to 2016 values, this comes to US $37.77 per barrel. However, the costs of extraction in the Arctic will be much higher, given the environmental and climatic extremes in this region. Given that we cannot identify information on these costs, we have assumed that the cost of extraction is 50% higher.

Table S4: Oil production values (2012 US$)

Oil producing region	Annual production (based on production in 2012) (millions bbls/year)	Annual revenue (2016 US$ billions)	Annual value (2016 US$ billions)
North slope, Alaska	0.20	1.98	8.07
Northwest Arctic	0.23	2.29	9.38
Total	0.43	4.27	17.45

Source of data: EIA (2010; 2013a; 2013b; 2014)

6. Hunting (cultural/identity)

Indigenous communities obtain welfare from hunting large mammals, through the strengthening of kinship ties and increased social capital from cooperation on the hunt. These all contribute to cultural and identity benefits. The only study to attempt to value these non-marketed aspects of the hunt is Olar et al., (2011). In an assessment of the socio-economic importance of polar bears to Canadian households, they estimated that the benefit of polar bear comes to about US$6,547 per adult hunter per year (in 2016 US$). In order to obtain an Arctic-wide value, it was assumed that all adult indigenous people in countries that allow polar bear hunting receive this cultural benefit from engaging in the polar bear hunt (PBSG, 2009). These countries include Canada (indigenous adult population: 0.04million), the US (Alaska) (0.081million) and Greenland (0.038million), which totals 157,846 adults (about 39.7% of the approximate 400,000 indigenous people in the Arctic).

The total number of bears hunted by non-sports hunters in 2012 came to 677 (total removals were 762, of which 85 were sold for sport hunting as per a quota system for trophy polar bear hunting in Canada) (see PBSG, 2013 for data on polar bear removals). It is worth noting that other hunts (e.g. whales, caribou) may also confer similar cultural and social capital values on hunting groups. However, there are no estimates of total cultural value of these hunting activities, so the value reported for polar bears will be considered indicative.

7. Tourism (cruise ship only)

For this section, only cruise-based tourism has been considered. Data on land-based expenditures has not been included in this valuation, so this value should be considered an underestimate. Part of the difficulty in identifying the value of Arctic tourism is that Arctic-specific trips are not differentiated in country-wide tourism statistics. This remains an area for future research.

The data for this section comes from Jorgenssen (2014), which provides data on cruises registered with the Association of Arctic Expedition Cruise Operators (AECO). AECO's core areas are Svalbard, Jan Mayen, Greenland, Canada and the national park "Russian Arctic" (Franz Josef Land and northern Novaya Zemlya). Two main Arctic cruise passenger type: expedition cruises, which involve Arctic-specific cruises varying in length from 7-19 passenger-days, and conventional cruises, with a 1-3day trip via the Arctic.

This estimate of tourism value uses a simple expenditure valuation approach: passenger numbers per cruise-day spent in the Arctic are multiplied by an average price of US$600 per passenger-day (calculated by author by averaging over the prices listed under the AECO members websites). It is assumed that Arctic expeditions spend an average 12 days, and conventional cruises spend an average 2 days in the Arctic. To calculate the net value of cruise tourism, I used a 10% profit margin reported for the cruise ship industry as a whole in a year (Statista, 2015).

Table S5: Cruise tourism values (2016 US$)

Cruise type	Number of passenger-days spent in the Arctic	Annual revenue (2016 US$ billions)	Annual value (2016 US$ billions)
Expedition to Arctic	163,075	0.09	0.01
Cruise via Arctic	188,164	0.11	0.01
Total	351,239	0.20	0.02

Source: Jorgenssen (2014) and Statista (2015) combined with own calculations

8. Climate regulation

Data for this section were obtained from Goodstein et al. (2010), who evaluate the impact that the loss of snow, ice, and permafrost will have on the earth's ability to manage its climate. The loss of ice and snow is exceptionally important because heat will not be reflected back out of the atmosphere (the albedo effect). Furthermore, permafrost stores large quantities of methane, which is a greenhouse gas. Using existing data on surface warming effects from the loss of snow, ice and permafrost, together with estimates of the amount of carbon dioxide released from permafrost melt, Goodstein et al (2010) construct a simple model that converts the additional planetary warming caused by these three effects into annual CO2 equivalents; economic estimates are then obtained using the social cost of carbon. Using this approach, Goodstein et al. (2010) estimate that Arctic snow, ice and permafrost contribute $61-371 billion per year (in 2010 US$) in terms of climate regulation services to the planet.

These annual values provided by Goodstein et al. (2010) have been used with only minor adjustments to account for inflation and possible double-counting of final services provided by ecosystems within the region. To avoid double-counting, some assumptions have been made with regards to the contribution of climate regulation to some of the final goods and services included in the study. It has been assumed that climate regulation is partially accounted for in the value of the following final goods: food (subsistence harvest and commercial fisheries), polar bear hunting, and the existence value of reindeer herding, beluga whales and polar bears. It is assumed that 50% of the full economic value of these final services has been provided by climate regulation services provided by Arctic snow, ice and permafrost, and this amount has been deducted from the climate regulation value. It is recognised that climate regulation may contribute different fractions of the full economic value of these final ES; however, in the absence of information regarding the relative contribution of climate regulation to each of these values, and given the importance of avoiding double-counting (Fu et al., 2011) we assume that 50% of the full value of these final services are provided by climate regulation services. Per capita values were produced using a population size of 7.4 billion (for 2016).

9. Existence values (cultural value of reindeer herding to non-herders)

This section used data from Bostedt and Lundgren (2010), which uses the contingent valuation method to estimate willingness to pay (WTP) amongst adult Swedish individuals for the existence of Swedish reindeer husbandry (by the Saami people) at the present level ('all or nothing' scenario). Given the highly skewed distribution of WTP values (typical of CV studies) reported in Bostedt and Lundgren (2010), I have chosen to use the median WTP estimates which range from $18.73 – 31.68 per year (in 2009 US$). To obtain Arctic-wide estimates, values were extrapolated to other relevant countries in which there is reindeer herding activity, in this case: Norway, Finland and Russia. To do this, values were multiplied by the adult populations of these countries (Norway, the adult population is about 3.81million, in Sweden: 7.36m, Russia: 114.8m; Finland: 4.18m.) and adjusted to 2016 US$ using PPP for each country.

10. Existence value of beluga whales

Data for this valuation was sourced from Boxall et al. (2012). They use CV to estimate WTP of Canadian households for different levels of conservation for belugas in the St Lawrence Estuary. Specifically, they estimate marginal utility changes for different levels of beluga whale conservation, compared to a current level of 1000 belugas (classed as "threatened"). We note that there is little variation in WTP over different levels of conservation, suggesting that perhaps respondents are not sensitive to varying levels of conservation but rather, are indicating a WTP for the existence of belugas. This kind of non-responsiveness to the scale or scope of a good is known as a part-whole bias (or embedding effect) and is considered to 4result from respondents valuing the overall existence of the good, rather than marginal changes in the status of the good.

It is therefore assumed that the estimated WTP results (which range from US$72.69 to $221.19 (adjusted from 2006 Canadian dollars to 2016 US$) are indicative of existence values for beluga populations among all *households* in Arctic nations with beluga populations which include Canada, Greenland, Norway (Svalbard), Russia and the U.S. (Alaska). Values were converted to per capita estimates by assuming 1.5 adults per household. Total estimated benefits were then calculated by multiplying per capita values by the number of adults in the various countries with beluga whale populations, including: Norway (number of adults in 2016 is 4.19million, Russia: 109.8m; Greenland: 0.404m; Canada: 28.39m; and U.S. 239.14.

11. Existence value of polar bears

(Olar et al. 2011) estimates the cultural benefit of hunting a polar bear to indigenous communities in Canada, although this is not based on primary data. Instead they use a model generated by Richardson and Loomis (2009) which is based on a meta-analysis of contingent valuation studies of endangered species (none of which included the polar bear). By inputting relevant values for key socio-economic and the resource variables into the model, they estimate that the existence value of polar bears to Canadian households comes to $508/household per year (in 2009 Canadian dollars) equivalent to US$475.20 (2016 $) when adjusted for PPP and inflation.

To obtain Arctic-wide estimates, values were extrapolated using a simple value transfer approach to other countries in which there are polar bear populations, in this case: Norway, Russia, Greenland and the U.S. (source: www.polarbearsinternational.org). Values were converted to per capita estimates by assuming 1.5 adults per household. Total estimated benefits *for Canadian residents only* were calculated by multiplying per capita values by the number of adults in Canada (28.39m).

12. Caveats, sources of error, limitations

1. This valuation omits a number of important goods and services, such as tourism expenditures on land, values associated with sport hunting, existence and bequest values for the Arctic as a whole, habitat/refugia services provided by sea-ice, amongst others. Primary data is being collected for some of the non-marketed values not included in this study; other data are simply not available.
2. This study does not take into account the dynamic and interrelated nature of ecosystems, the relationships between resource uses or changes in environmental conditions, or the long-term sustainability of resource uses. This is a major limitation of most economic valuation studies like this one, and so results presented here must be considered within light of this static approach.
3. The preference at all times is to identify consumer surplus plus producer surplus, which should reflect the 'true' economic value of the various ecosystem goods and services being treated here. However, consumer surplus data is difficult to obtain for marketed goods unless we have a good grasp of the demand curve for these goods. Therefore, this paper has mostly presented the net rent (producer surplus), which means a potentially significant portion of economic value is missing. However, this can be considered indicative of the value of the resource from the producer point of view.
4. Estimates presented here are based on values from existing studies, and these use a variety of methods for valuation, which in some cases limits comparability.

Nonetheless, in the absence of more and better data, this study represents a first step at identifying the value of what the Arctic currently provides, and hence the value of what might potentially be lost given a certain scenario of climate change.

13. Sources of Data for Population Statistics

Population statistics for each country were for the year 2016, except for Russia which is for mid-2015 and Finland which is for 31st December 2015. Data on population size was obtained from National statistics offices, including:

Statistics Canada (2016) CANSIM, Population by sex and age group table [051-0001]. Available on: http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/demo10a-eng.htm

Official Statistics of Finland (OSF) (2016) Population structure [e-publication]. ISSN=1797-5395. Helsinki: Statistics Finland. Accessed on: http://www.stat.fi/til/vaerak/index_en.html

Statistics Norway (2016) Population – summary tables (Resident population at population censuses (SY 47)). Available on: https://www.ssb.no/en/befolkning/nokkeltall/summary-tables

Russian Federation Federal State Statistics Service (2015) Table 5.2 Population by age groups. Available on: http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/en/figures/population/

Statistics Sweden (2016) Preliminary Population Statistics, by month, 2016. Available on: http://www.scb.se/be0101-en

US Census Bureau (2016) National Population Totals Tables: 2010-2016. Monthly Population Estimates for the United States: April 1, 2010 to December 1, 2017 (NA-EST2016-01). Available on: http://www.census.gov/data/tables/2016/demo/popest/nation-total.html

Data on indigenous populations of Alaska were obtained from the United States Census Bureau (2016) Quick Facts on Alaska. Available on: http://www.census.gov/quickfacts/table/PST045216/02#headnote-js-a

Data on indigenous populations of Greenland were obtained from:: http://www.iwgia.org/regions/arctic/greenland and https://www.cia.gov/library/publications/the-world-factbook/geos/gl.html

Data on indigenous populations of Canada were obtained from Statistics Canada (2011) Aboriginal Peoples in Canada: First Nations People, Métis and Inuit, National Household Survey, 2011. Available on http://www12.statcan.gc.ca/nhs-enm/2011/as-sa/99-011-x/99-011-x2011001-eng.pdf

Table S6. Major Mines in Greenland

Mineral Resource	Mine	Mine Life	Expected Beginning Date	Expected Ending Date	Projected Flow
Uranium	Kvanefjeld project	23 years	2018	2041	11.339mn kg/year
Rare Earth Elements	Kvanefjeld project	23 years	2018	2041	407.049mn kg/year
Rare Earth Elements	TANBREEZ	N/A*	2015	N/A*	100mn kg eudialyte/year, 200mn kg feldspar/year
Iron Ore	Isua Deposit	10 years	2015	2025-2030	16,200mn kg/year
Zinc	Kvanefjeld project	23 years	2018	2041	88.746mn kg/year
Zinc	Citronen Project	14 years	2016	2030	185.677mn kg/year
Lead	Citronen Project	14 years	2016	2030	48.045mn kg/year

*Theoretically, TANBREEZ has a mine life thousands of years, as the mines hold an estimated 4.3 billion tonnes of minerals. There is insufficient data on TANBREEZ's realistic mine life, though.

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Vilhjálmsson, A. & Hoel, H. (2013) 'Fisheries and Aquaculture.' In: Hassol, S.J. (ed) Impacts of a Warming Arctic-Arctic Climate Impact Assessment, Arctic Climate Impact Assessment (ACIA), Cambridge, UK: Cambridge University Press, pp 692-780