CO_2 vs. Salmon: Complementary Policies In Wheat Transportation In The Pacific Northwest?

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Word Count: 5,508 (4, 008 + 1500 for 6 tables)

ABSTRACT
Global climate change is one of the most debated environmental issues of the 21st century. Carbon dioxide (CO_2) is the principal contributor to climate change. Higher levels of CO_2 concentrations are primarily the result of burning of fossil fuels such as petroleum, coal and natural gas. Simultaneously, salmon populations are now being threatened and endangered. One technique to restore the salmon is the potential drawdown of the Snake River in Washington State. But, a paradox arises because this effort may increase the CO_2 production by trucks and rail as barge transportation is stopped on the river.

This paper uses wheat and barley transportation, the largest user of barge, to examine the impact on energy consumption and associated CO_2 production if the river is breached and barge transportation ceases. A GIS-GAMS transportation model examines the pre and post breaching least cost wheat flows for the producer. Significant increases in rail movements are seen, with some increases in truck in a feeder role to the rail. The relative modal energy intensity coefficients affect the energy consumed. Overall results indicate that the paradox continues with breaching causing some increase in CO_2 levels, especially for the barley movements (41%) and overall (1.61%), while offering the possibility of some perceived benefit to the endangered salmon stocks.

INTRODUCTION

Global climate change (GCC) is one of the more debated environmental issues of the 21st century. Significant changes to natural systems such as receding glaciers, rising sea levels, and increasing storm severity from global warming may have profound effects on many regions around the world. Weather fluctuations and natural disasters could likely disrupt food and water supplies, damage ecosystems (including crops and forests), and increase disease and illnesses. Human systems such as agriculture, fisheries, and water provisioning are particularly vulnerable to droughts, flooding, heat waves, hurricanes and other climate changes.

The scientific consensus is that the planet is warming due to human activity *(1, 2, 3)*. Although the planet is naturally warmed by greenhouse gases (GHGs), which makes the Earth hospitable for its inhabitants, the rise in atmospheric GHG concentrations from anthropogenic sources is warming the planet at a rate greater than would be expected naturally and is considered to be the leading cause of human induced climate change *(3, 1)*. Carbon dioxide (CO_2) is a principal GHG and the main contributor to anthropogenic climate change. Since the Industrial Revolution, atmospheric concentrations of CO_2 have increased more than 30% *(3)*. Higher levels of CO_2 concentrations are primarily the result of burning of fossil fuels such as petroleum, coal and natural gas. In the U.S., roughly 98% of CO_2 emissions are from burning fossil fuels *(4)*. Two other important GHGs, methane (CH_4) and nitrous oxide (N_2O), have also increased due to human activities. Methane (CH_4) concentrations have more than doubled, and nitrous oxide (N_2O) levels have increased by 15% *(3)*. The greatest percentage of all anthropogenic GHG emissions, however, is CO_2 from fossil fuel combustion. According to the Energy Information Administration, in 2001, CO_2 made up 82 percent of human-made GHG emissions in the U.S. *(5)*. Therefore, efforts to slow global warming have generally focused on reducing CO_2 emissions.

Although climate changes will undoubtedly have considerable global effects, there will also be variable and significant regional impacts. In the Pacific Northwest, snowpack levels on the Cascade Mountains are expected to decline due to global warming *(6)*. Forecasting climate changes through 2100, Ghan and Shippert *(6)* estimate that the Cascade Range will retain only 57 percent of current snowpack levels at the end of the century. In addition, Pacific Northwest regional temperatures could increase by 1 to 4.5 degrees Fahrenheit (0.5 – 2.5 °C) by the 2020s, and 2.7 to 5.8 degrees Fahrenheit (1.5 – 3.2 °C) by the 2040s *(7)*. Decreasing snow pack and increasing temperatures from climate change are predicted to cause early spring snowmelt, increase winter stream flow and decrease summer stream flow, which will result in less water for irrigation, fish, and hydropower production in the summer months *(8)*. For Washington State, warmer temperatures, severe droughts, floods, and rising sea levels are expected to negatively impact ecosystems, agriculture, forestry, and fisheries *(9)*.

Salmon and Climate Change

Salmon populations are particularly vulnerable to climate changes since warming trends are likely to have detrimental effects to freshwater habitats, which may further threaten salmon survival *(10)*. Currently, several species of salmon in the Columbia-Snake River are threatened or endangered *(11)* and regional climate changes could exacerbate already marginal conditions for salmon in the Pacific Northwest. Reduced stream flows from early snowmelt and rising water temperatures will worsen river conditions, making freshwater river habitats less hospitable for the threatened and endangered salmon.

Salmon are anadromous fish that live most of their lives at sea but travel to freshwater to spawn. Each spring, adult salmon leave the ocean and return to the Columbia-Snake River to lay eggs in freshwater. As juveniles, the salmon swim down river and spend many years in the ocean before traveling back up river. Dams along the Columbia-Snake River have made salmon migration more difficult, both for adults traveling upstream and juveniles making their way back to the ocean. Technological fixes, such as fish ladders, have been added to dams to help adult salmon swim upstream and barges have been used to transport juveniles downstream on their return to the ocean. Despite these efforts, salmon populations have not had a strong recovery, and many species still remain threatened or endangered. Therefore, additional efforts, such as dam-breaching, have been considered to increase salmon numbers and to restore vitality to river ecosystems. Specifically, it has been proposed that breaching four dams along the Snake River will alleviate navigation obstacles and improve salmon habitats *(12)*.

There are eight dams located along the lower Columbia-Snake River but only the four dams along the Snake River are being considered for breaching. The four proposed dams are the Lower Granite, Little Goose, Lower Monumental, and Ice Harbor, which are located on the Snake River in Eastern Washington between Pasco, Washington and Lewiston, Idaho. In the 1990s, there was strong support for breaching from environmental groups and Native American tribes; however, dam-breaching was ultimately not included as part of the federal salmon recovery plan in 2000. New legislation, however, was recently introduced by members of the House to revisit the dam breaching issue. The Salmon Planning Act (HR 1615), originally introduced in 2003 and then reintroduced it in 2005, was drafted to investigate the effectiveness of the federal recovery plan. The aim of the Salmon Planning Act is to analyze the economic impacts of dam removal, as well as the impacts to communities, transportation, irrigation, energy production, salmon and steelhead *(13)*. Furthermore, it is written to provide Congressional authority for dam removal if it is determined to be necessary *(13)*.

An Environmental Paradox

Despite possible beneficial outcomes for salmon populations and river ecosystems, dam-breaching can also have unanticipated environmental consequences. Several studies have noted that dam-breaching produces an environmental paradox (see, for example *14, 15*). For example, even though dam-breaching could potentially help salmon recovery and river ecosystems, Lee and Casavant *(14)*, using national energy model consumption coefficients, found that it would also likely have unwanted environmental impacts because a modal shift away from barge would affect both energy consumption and emissions. Ball and Casavant *(15)* using regional energy coefficients, found a drawdown of the Snake River for salmon restoration would not have a significant energy or emissions environmental effect.

Barges are cost-effective, primary movers of goods along the Columbia-Snake River. According to Makaryan et al. *(16)*, barges transport 40 different types of commodities, with an average of 2.5 million tons moving downstream and 7.4 million tons moving upstream between the years 1995 and 2003. Consequently, any reduction in barge transport would unsurprisingly cause a greater reliance on truck and rail transportation. Ball and Casavant *(15)* concluded that a modal shift after dam-breaching would somewhat increase both energy use and net emissions of several key pollutants including, nitrogen oxides (NO_X), carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM). Sulfur oxides (SO_X) were the only pollutant shown to have a net decrease in emissions levels after dam-breaching.

In their study, Ball and Casavant analyzed emission changes of common diesel fuel pollutants; however, carbon dioxide (CO_2) emissions, the major contributor to global warming, were not included. Although not generally considered an air pollutant, CO_2 emissions have serious environmental consequences. As discussed previously, CO_2 is a primary greenhouse gas linked to human caused global climate change (GCC). In addition, the transportation sector is a main contributor of anthropogenic greenhouse gases (GHGs). Of total CO_2 emissions, approximately one-third comes from the transportation sector, with about 20% from middle distillates (diesel fuel) used to power heavy trucks, trains, and barges *(4)*. According to the World Resources Institute, over the last 30 years the share of CO_2 emissions from the transportation sector has increased at a faster rate than the other sectors *(17)*.

Changes in CO_2 emission if the four dams were to be breached along the Snake River was the focus of the study. First the regional energy use calculations presented by Ball and Casavant were compiled. Then a CO_2 intensity model was created by combining energy use with CO_2 contributions per unit of energy. Finally, changes in CO_2 emissions for wheat and barley transported by barge, rail, and truck were calculated, allowing evaluation of how one salmon restoration technique, dam breaching, might affect the atmosphere.

METHODS AND DATA

The GIS-GAMS Model and Energy Use

Since grain makes up a sizeable percentage of barge transportation, the loss of this mode will have considerable effects on transport patterns, and related energy use, and emissions. Wheat accounts for roughly 70% of all tons of materials transported downstream *(16)*. In addition, barge delivers about 40% of the grain receipts recorded at Columbia River export terminals *(18)*.

The Geographic Information System (GIS) database and Generalized Algebraic Modeling System (GAMS) model, developed by Eric Jessup *(12)*, estimates wheat and barley transport mileage using GIS data and a least cost minimization model to assess changes in modal shifts before and after dam-breaching. In order to build the GIS coverage of road and transportation networks, data were combined from the Washington State Department of Transportation (WSDOT) and the U.S. Census Bureau Topological Integrated Geographic Encoding and Referencing (TIGER). To account for transportation flow constraints of each mode, least cost modeling estimates of grain flow volume from the original grain supply locations, to intermediate locations (e.g., a grain elevator), and to the final destination were calculated. From these calculations, Jessup was able to estimate ton-miles for each transportation mode (rail, barge, and truck) for a Reference Case that includes barge use, and a Breaching Case that accounts for the reduction in barge miles (see *12, 14 and 15* for full reviews of the Jessup GIS-GAMS Model).

In this paper, the regional energy estimates for the Reference Case and Breaching Case as presented by Ball and Casavant *(15)* from the GIS-GAMS mode are used. Ball and Casavant first calculated energy-efficiency coefficients based on economic-engineering reports provided in interviews with operating rail and barge firms currently active on the Columbia-Snake River. Then, the energy coefficients were applied to wheat and barley movements in Eastern Washington using the Jessup GIS-GAMS model, accounting for modal shifts and transportation patterns. Since the GIS-GAMS model presents estimates as ton-miles, the number of British Thermal Units (BTUs) per ton-mile was multiplied by the number of ton-miles for each mode of transportation to calculate total BTUs consumed in the Reference and Breaching Cases. The number of BTUs consumed by each transportation mode varies considerably. Truck is the least energy-efficient, using 549 BTUs per ton-mile. By contrast, rail is the most efficient, using 278 BTUs per ton-mile. Barge uses about 366 BTUs per ton-mile *(15)*.

Carbon Dioxide Emissions Estimates

Emissions estimates were calculated based on the number of pounds of CO_2 emitted from burning of one gallon of fuel (see *19*). According to the U.S. Department of Energy - Energy Information Administration (DOE/EIA), 22.4 pounds of CO_2 is emitted for every gallon of diesel fuel burned. Using the known British Thermal Units (BTUs) consumed for the Reference and Breaching Cases as presented by Ball and Casavant *(15)*, the number of gallons consumed by each transport modal was multiplied by dividing total BTUs by the number of BTUs per gallon of fuel (138,691 BTUs per gallon of diesel fuel). From this CO_2 emissions for each mode of transportation were obtained and analysis of the changes in CO_2 emissions for Reference and Breaching Cases was undertaken. Changes in emissions for both wheat and barley transport along the Columbia-Snake River were detailed.

RESULTS

Wheat

Energy use changes for the Reference and Breaching Cases are shown in Table 1.1. Ball and Casavant *(15)* found that overall energy use decreases by roughly two percent after the loss of barge. Rail energy consumption increases by more than by 73,280 million BTUs, the greatest change in energy use after barge. Truck energy use changes much less, increasing 32,567 million BTUs. This indicates that for wheat, rail picks up more of the transport and volume in the Breaching Case. For wheat transport, there is a reduction of 12,816 million BTUs when comparing the difference between the Reference and Breaching Cases. As a result, the loss of barge transportation was found to not increase overall energy use for wheat.

Table 1.1 British Thermal Unit (BTU) Consumption for Wheat Transport (in tons)

Mode	BTU Reference	BTU Breach	Difference	Percent Change
Truck	210,556,997,721	243,124,282,719	32,567,284,998	15.47%
Rail	78,369,579,158	151,650,192,898	73,280,613,740	93.51%
Barge	302,844,475,818	184,180,392,822	-118,664,082,996	-39.18%
Total	591,771,052,697	578,954,868,439	-12,816,184,258	-2.17%

Source: Adapted from Ball and Casavant *(15)*

As would be expected, total CO_2 emissions for both the truck and rail modes increase, while emissions from barge stop in the Breaching Case (see Table 1.2). Altogether there is a net reduction in CO_2 emissions and over 2 million fewer pounds of CO_2 are released into the air.

Table 1.2 Carbon Dioxide (CO_2) Emissions for Wheat (in pounds)

Mode	CO_2 Reference	CO_2 Breach	Difference	Percent Change
Truck	34,007,086	39,267,032	5,259,946	15.47%
Rail	12,657,480	24,493,041	11,835,561	93.51%
Barge	48,912,448	29,746,997	-19,165,450	-39.18%
Total	95,577,014	93,507,070	-2,069,943	-2.17%

For wheat, elimination of barge as a mode of transportation as a result of the dam breaching brings about lower energy consumption and CO_2 emissions (-2.17%), which may be attributed to the relative stronger energy efficiency of rail over truck. Rail is more energy-efficient than truck and uses fewer BTUs per ton-mile. Truck had been used to move grain to the barge facilities, sometimes song distances. Truck transport uses about 549 BTUs per ton-mile, while rail only uses 278 BTUs per ton-mile. Therefore, per ton-mile, rail directly also produces fewer emissions than truck. In other words, after the loss of barge as a mode of transportation, greater reliance by shippers on rail in a cost minimization effort, has less detrimental environmental outcomes than would the same reliance on truck transport.

Barley

Energy use increases for barley by a total of 23,258 million BTUs when comparing the Reference and Breaching Cases (see Table 2.1). Although the percent change is higher for rail, the absolute change in energy use is much greater for truck, since truck is more often used for barley than rail. The increase in truck mileage is 55,997,597 miles, which corresponds with an increase of 30,742 million BTUs. Rail transport, however, only increases by 55,817 miles for an energy increase of just over 15 million BTUs. Overall, the loss of barge increases energy use for barley transport.

Table 2.1 British Thermal Unit (BTU) Consumption for Barley Transport (in tons)

Mode	BTU Reference	BTU Breach	Difference	Percent Change
Truck	28,605,495,672	59,348,176,425	30,742,680,753	107.47%
Rail	10,339,376	25,856,502	15,517,126	150.08%
Barge	27,931,386,990	20,431,971,594	-7,499,415,396	-26.85%
Total	56,547,222,038	79,806,004,521	23,258,782,483	41.13%

Source: Adapted from Ball and Casavant *(15)*

For barley, there is also an increase in CO_2 emissions (Table 2.2). Altogether, an additional 3.8 million pounds of CO_2 are emitted into the atmosphere when comparing the Reference and Breaching Cases. Again, while emissions more than doubled for both truck and rail, the absolute increase in CO_2 emissions was much greater for truck with its longer hauls in this scenario. After the loss of barge, truck transport emits almost 5 million more pounds of CO_2 into the air, while rail emits only about 2,500 additional pounds.

Table 2.2 Carbon Dioxide (CO_2) Emissions for Barley (in pounds)

Mode	CO_2 Reference	CO_2 Breach	Difference	Percent Change
Truck	4,620,077	9,585,331	4,965,254	107.47%
Rail	1,670	4,176	2,506	150.10%
Barge	4,511,202	3,299,970	-1,211,231	-26.85%
Total	9,132,949	12,889,477	3,756,529	41.13%

Although losing barge as an option decreases CO_2 emissions from barge by over 1 million pounds, the large increase in truck emissions negated any gains. In this case, however, the modal shift from barge to an increased reliance on truck's movements (a combination of higher energy use per ton-mile and longer truck hauls for barley) can account for some of the difference. In effect, the additional use of truck can account for both the increase in energy use and CO_2 emissions.

Wheat and Barley Combined

Here the combined effect of losing barge transportation along the lower Snake River for wheat and barley is presented. Energy use increases slightly over 1.6% when the total market is considered (Table 3.1). In these simulations, 10,442 million additional BTUs will be consumed after the four dams are breached.

Table 3.1 British Thermal Unit (BTU) Consumption for Wheat and Barley (in tons)

Mode	BTU Reference	BTU Breach	Difference	Percent Change
Truck	239,162,493,393	302,472,459,144	63,309,965,751	26.47%
Rail	78,379,918,534	151,676,049,400	73,296,130,866	93.51%
Barge	330,775,862,808	204,612,364,416	-126,163,498,392	-38.14%
Total	648,318,274,735	658,760,872,960	10,442,598,225	1.61%

Source: Adapted from Ball and Casavant *(15)*

Carbon dioxide emissions also increase in direct proportion (Table 3.2). These estimates show an addition of nearly 1.7 million pounds of CO_2 into the atmosphere. The movements by barge show a decrease of over 20 million pounds of CO_2 emissions when comparing the two cases, but truck and rail emissions increase 10 million and almost 12 million pounds respectively, yielding the net increase of nearly 1.7 million pounds (1.61%) of CO_2.

Table 3.2 Carbon Dioxide (CO_2) Emissions for Wheat and Barley(in pounds)

Mode	CO_2 Reference	CO_2 Breach	Difference	Percent Change
Truck	38,627,163	48,852,363	10,225,200	26.47%
Rail	12,659,150	24,497,217	11,838,067	93.51%
Barge	53,423,649	33,046,967	-20,376,682	-38.14%
Total	104,709,962	106,396,547	1,686,585	1.61%

The difference in emissions and energy use between the alternate modals is directly related to the length of haul and alternative energy consumption per ton–mile. In the breaching simulation, truck carrying distances increase overall by about 115 million miles. Rail mileage, at 264 million miles, is more than double that of truck, yet rail only uses about 10,000 million more BTUs and emits only 2 million more pounds of CO_2 than truck, due to its relative energy efficiency. Although the combined total of these two grains shows an overall increase in energy use and CO_2 emissions under a possible breaching scenario, a modal shift that would include increased reliance on rail could reduce the negative environmental impacts of losing barge.

CONCLUSION

Dam-breaching is considered a viable adaptation option for salmon recovery in response to climate and human induced environmental change, since it would likely improve their habitat by reducing river water temperatures and affecting river environments in the short term *(10)*. The paradox is that dam-breaching could also generate higher levels carbon dioxide (CO_2) emissions. Therefore, while dam-breaching may have positive effects on salmon habitats, possible negative environmental consequences would need to be mitigated with concurrent policies and programs specifically addressing transportation changes if the four Washington dams are breached.

The results of this research indicate that higher reliance on rail after losing barge, would possibly mitigate some of the potential negative environmental impacts. Rail transport is the most efficient in terms of energy use and consequently releases fewer CO_2 emissions per ton mile. Therefore, options to increase rail's competitive position with truck in the shipper's business model, could potentially reduce emissions levels. For example, in Washington State, the Grain Train Program provides additional rail cars to increase carrying capacity, thereby reducing the demand for less-efficient truck transport *(20)*. Further, policies to increase the physical and operational capacities of Washington States' railroad system offer possibilities of addressing some emissions and energy use; these policies could lessen or eradicate this environmental paradox.

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