Appendix: Transportation-to-market break-even distances

Methods

Transportation break-even distances with respect to the carbon footprint (CF) of crops (canola, non-durum wheat, and field peas) produced in Saskatchewan and transported to each overseas destination (France, Germany, Australia) compared to the production of the same crops in the destination countries were calculated. Saskatchewan was chosen as the production location of origin for this comparison since Saskatchewan field crops generally had lower CF than the same crops produced in each other country. First, the differences between the carbon footprints of production (both with and without SOC) of each crop type in Saskatchewan compared to each other country were calculated. For example:

$CF\ per\ tonne\ of\ Australian\ wheat\ (SOC\ included) - CF\ per\ tonne\ of\ Saskatchewan\ wheat\ (SOC\ included) =$

$$591.27\ kg\ CO_2e - 214.09\ kg\ CO_2e = 377.17\ kg\ CO_2e$$

Then, the impacts of transportation from Saskatchewan to port in Canada were calculated (Table 1). These transportation distances were based on personal communication from Pulse Canada regarding the transportation routes for peas, and assumed to be equivalent for wheat and canola.

Table 1. Transportation distances and associated carbon footprint for land transportation within Canada from Saskatchewan to port.

	Thunder Bay	Vancouver
Truck (km transported)	150	150
Train (km transported)	1438	1201
Carbon footprint (kg CO_2e per tonne transported to port)	89.48	78.12

These land transportation impacts were subtracted from the difference in production impacts, for example:

$$Difference\ between\ SK\ and\ AU\ CF\ per\ tonne\ wheat - land\ transportation\ of\ 1\ tonne\ SK\ wheat\ to\ port\ in\ Vancouver =$$

$$377.17\ kg\ CO_2e - 78.12\ kg\ CO_2e = 299.05\ kg\ CO_2e$$

Then, this remaining difference in CF was divided by the CF per t*km of bulk vessel transportation (sourced from ecoinvent v.3.8), to determine the total kilometers that each SK crop could be shipped by bulk vessel before breaking even with the impacts of producing that crop locally. For example:

$$\frac{Difference\ between\ SK\ production\ plus\ land\ transport\ and\ AU\ production\ per\ tonne\ wheat}{Impact\ per\ t * km\ bulk\ vessel\ transportation} =$$

$$\frac{299.05\ kg\ CO_2e\ per\ t}{0.0065\ kg\ CO_2e\ per\ t * km} = 46079\ km$$

Next, the actual distances to ship from the relevant Canadian port to the nearest port in each country were subtracted from the break-even distances, for example:

$$Break\ even\ distance\ for\ wheat\ SK\ to\ AU - Transportation\ distance\ Vancouver\ to\ AU =$$

$$46079\ km - 33340\ km = 12739\ km$$

If the break-even distance was higher than the shipping distance, this means that the impacts of producing the crop in Saskatchewan and shipping it to the other country were still lower than local production in that country, and vice-versa. The leftover transportation distances (break-even minus actual shipping distance) were then expressed as the number of trips from Saskatchewan to the country, and as circumnavigations of the globe. For example:

$$\frac{Leftover\ transportation\ distance\ for\ SK\ wheat\ to\ AU}{Shipping\ distance\ Vancouver\ to\ AU} =$$

$$\frac{12739\ km}{3340\ km} = 0.38\ Additional\ trips\ to\ AU\ before\ breaking\ even$$

$$\frac{Leftover\ transportation\ distance\ for\ SK\ wheat\ to\ AU}{Circumference\ of\ globe} =$$

$$\frac{(12739\ km)}{40075\ km} = 0.32\ Additional\ circumnavigations\ of\ the\ globe\ before\ breaking\ even$$

See attached Excel file for all calculations.

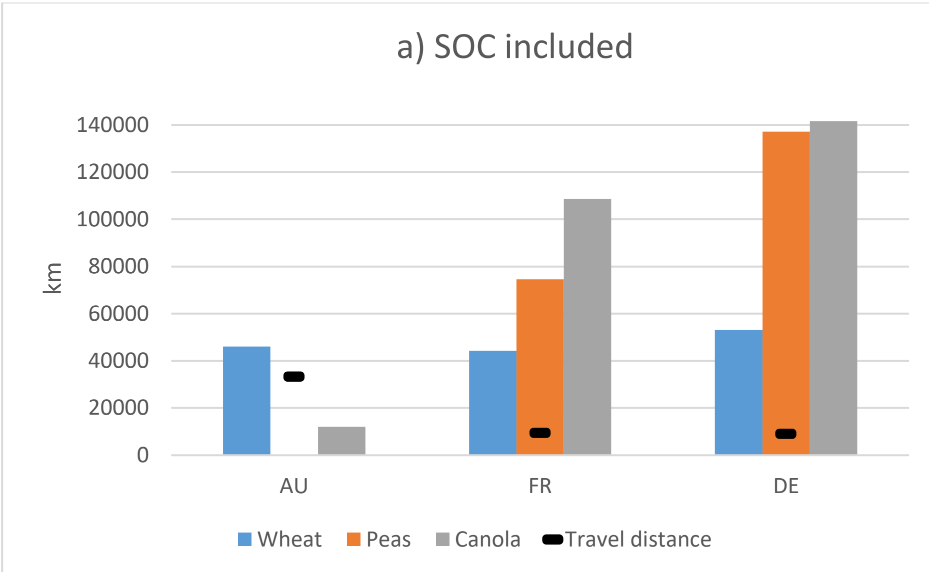
Results

When soil carbon was included, wheat, canola and peas produced in Saskatchewan then shipped overseas to Australia, France, and Germany still had lower CFs than crops produced in each destination country, with the exception of Australian canola (Figure 1a). In the most extreme cases, differences in production emissions were sufficient to offset shipping the crops from Canada to Europe an additional 14 times before breaking even (for German peas and canola), equivalent to circumnavigating the globe more than three times (Figures 1a and 2). On the other hand, Australian canola had only slightly higher impacts of production (with SOC included) compared to SK canola, therefore the bulk vessel transportation distance to break-even was less than the actual transportation distance. This indicates that despite the lower production impacts in SK, the CF would be higher to transport canola from SK to Australia, due to the additional transportation impacts.

With soil carbon included, transportation accounted for 14–77% of the impacts of Saskatchewan crops shipped overseas. This proportion varied with the relative carbon intensities of production for each crop, as well as the different transportation distances to each destination country. Saskatchewan peas had the lowest carbon footprint of all the crop types, therefore transportation made the highest proportional contribution, ranging from 47% of the impacts for transport to Germany, to 77% for peas shipped to Australia. In contrast, Saskatchewan wheat had higher impacts of production than peas, so transportation contributed a lower percentage to the total carbon footprint (22% to France and Germany, and 50% to Australia). Rapeseed had the highest impacts of production of the three crops produced in Saskatchewan, and thus transportation only made up 14-37% of the total carbon footprint to market in Europe/Australia.

With soil carbon excluded, transportation accounted for 18-44%, 14-38%, and 9-27% of the impacts of shipping Saskatchewan peas, wheat, and rapeseed to Europe/Australia. For Saskatchewan crops, the exclusion of soil carbon meant higher overall impacts of production, since Saskatchewan soils had net carbon sequestration. Therefore, transportation overseas made a relatively smaller contribution.

However, when calculating the break-even distances without SOC change, differences in production-related emission between countries were lower. This is because Canadian crops had net SOC sequestration, and all other countries had net SOC loss, meaning that when the SOC-related impacts are not included, Canadian impacts are higher and other countries' impacts are lower, thus reducing the gap between Canada (Saskatchewan) and other countries. Therefore, without SOC included, transportation of Canadian crops was proportionately more important in determining the break-even distances and relative sustainability of imported Canadian crops compared to locally produced crops in France, Germany, and Australia (Figure 1b). Without SOC change, Saskatchewan canola and peas shipped to Europe still had lower emissions than crops grown in France or Germany, with the exception of French peas. For German canola and peas, the offset was still sufficient to ship the crops produced in Saskatchewan to Germany an additional four times before breaking even, almost one circumnavigation of the globe (**Figure 2**). However, for wheat, the break-even distances were all less than the actual transportation distances, indicating that (if SOC is not included) it is not more sustainable from a GHG emissions perspective to ship Saskatchewan crops overseas. Taken together, these results highlight that, despite the higher importance of transportation when SOC was excluded, the differences in production emissions can still be large enough to more than offset the transportation emissions, but not in all cases.



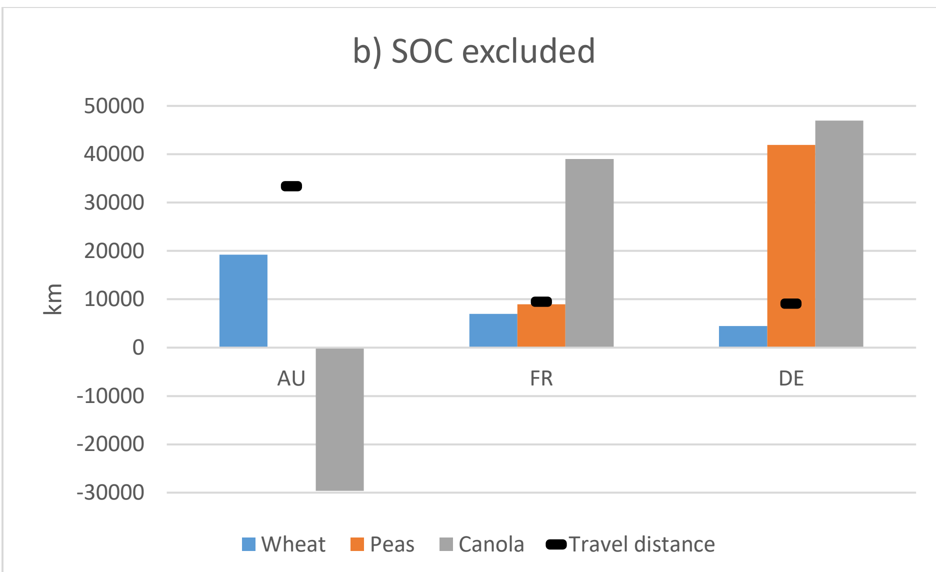


Figure 1. Break-even distances with respect to the carbon footprint of Saskatchewan wheat, peas, and canola transported to Australia, France, and Germany, compared to the actual travel distance to each destination country. The break-even distances represent the amount of ocean transport possible before the emissions from transportation break even with the difference in production emissions between regions. A negative break-even distance means that production emissions in the destination country are lower than in Saskatchewan. Results are presented with SOC change a) included in, and b) excluded from the production emissions.

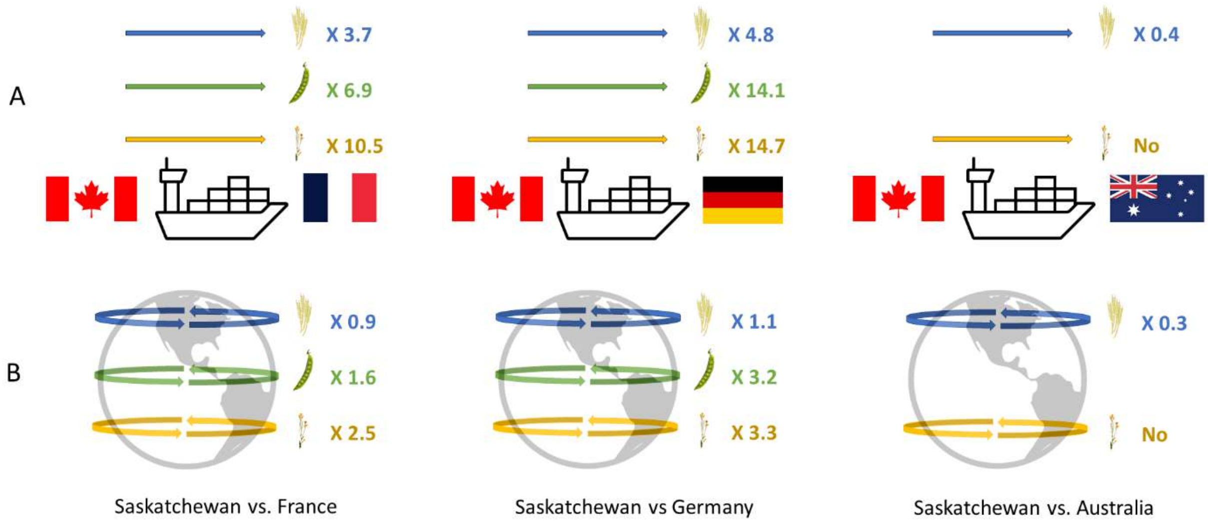


Figure 2. For Saskatchewan wheat, peas and rapeseed, the number of a) extra trips from Saskatchewan to the destination country that could be taken before reaching the break-even distances (with soil carbon included), and b) equivalent distances represented as trips around the world.