Response to Comment on "Using Nested Average Electricity Allocation Protocols to Characterize Electrical Grids in Life Cycle Assessment: A Case Study of U.S. Primary Aluminum Production"

We are pleased to take this opportunity to respond to Christoff Koffler, Jinlong Marshall Wang, and Kurt Buxmann's comments regarding our article "Using Nested Average Electricity Allocation Protocols to Characterize Electrical Grids in Life Cycle Assessment: A Case Study of U.S. Primary Aluminum Production" (Colett et al. 2016). Koffler and colleagues (2016) indicate that our article "provides good insights into the challenges associated with quantifying GHG emissions from electricity consumption," which was our aim. Our objective in the article was to create and apply an allocation method that enables LCA practitioners to estimate emission factors for electricity consumption using public data while balancing accuracy and modeling complexity.

This research was conducted as part of a DOE Clean Energy Research Center Clean Vehicle Consortium project to study greenhouse gas emission impacts of vehicle electrification and lightweighting strategies, including material sourcing decisions. We focused on the U.S. primary aluminum industry as a case study because of its electricity dependence, enabling us to study the sensitivity of emission factors to the allocation method used. We make no claim that our case study GHG estimates should be used as standards, but present them in comparison to previous estimates produced via other methods to highlight the importance of the choice of allocation method on results.

Scope

We acknowledge in our article the interconnected nature of aluminum production in the U.S. and Canada (U.S. Primary Aluminum Case Study – Methods, first paragraph). However, when electricity-intensive production locations are distributed across grid regions with different carbon intensities, aluminum ingot will be produced with different emission factors depending on location. We do not agree that applying a North American average emission factor reconciles this conflict. While continental average energy consumption and GHG emissions are likely representative for high volume components produced from primary aluminum ingot, accounting for details of each step in the process chain associated with making products is an essential component of LCA. One of the primary objectives of LCA is improvement in product environmental performance, which can only be achieved by

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identifying where in their process chains the major burdens occur. Our treatment of energy and emissions for local and regional electricity production is a step in this direction.

Separating U.S. and Canadian emission factors is necessary to compile accurate national carbon accounts. This is not the artificial separation Koffler and colleagues contend, but a logical and reasonable step to avoid misrepresenting both U.S. and Canadian emissions by using a North American average. Identifying spatial differences in emission factors is important for producers and others in the supply chain who are engaged in identifying the most effective carbon mitigation strategies related to aluminum production. Indeed, identifying and correcting the process steps and facilities with the highest emissions would make industry averages more representative and reduce the potential for spatial discrepancies pointed out in our article.

We estimate plant-level emission factors to compare with average emission factors and not to improve on previous plant-level characterizations, which Koffler and colleagues rightly state in their letter haven't been produced before. We include average emission factors from PE America's well-cited Life Cycle Assessment of Aluminum Beverage Cans study, though we are concerned by their assertion that "According to the IAI statistics (IAI, 2007), the power mixes representative for the U.S. and Canada are of the same composition, as they both belong to the category North America." This loosely-worded statement may have led others to believe that Canadian- and U.S.-sourced aluminum production emission rates were the same, and equal to the North American average, when this is not the case.

Methods

Koffler and colleagues incorrectly characterize our method as one that combines eGRID subregion emission factors with FERC-714 trade data. In our new method, we used trade data to estimate the amount of electricity imported and exported between power control areas (PCAs) and the larger NERC regions that they are nested within. eGRID subregions are larger, non-nested regions that do not allow the application of our method. The approach Koffler and colleagues describe sounds promising and we look forward to a publicly available peer-reviewed publication that fully describes it.

In regards to allocation protocols, Koffler and colleagues present the GaBi and ecoinvent approach as "current best practice." While this approach is certainly common, it is one of many methods currently used and we view this topic as far from settled. Indeed, this lack of agreement was one of the primary drivers of our work. There are a wide range of models and methods available for estimating electricity emissions, from simplified emission factor approaches to detailed statistical models, as well as prospective dispatch models that are further segmented into economic dispatch, unit commitment, and capacity planning subtypes. We believe that we have made a useful contribution to the debate in this area with our paper.

With regard to Alcoa's Warrick, Indiana smelter, and as described in the Methods section of our paper, we used the emission factor of Warrick's on-site coal-fired power plant as reported in eGRID 2012 instead of the emission factor from the surrounding power control area.

Data

Koffler and colleagues raise the issue of newer information that is missing from our paper, including one reference to a Power Point presentation (Koffler et al. 2013). We used the most current peer-reviewed journal articles and information available at the time of writing. The availability of newer information since submission, peer-reviewed or not, doesn't invalidate our approach. The decommissioning of the Hannibal smelter between submission and publication of our paper would alter results and this knowledge should certainly be part of future work, but again, it does not weigh against our method.

The data and results we present for the Warrick facility attracted some scrutiny from Koffler and colleagues. Acknowledging that measured data are preferable to estimates, estimates are necessary when measured data are not publicly available. We estimated the Warrick smelter to have an electricity intensity of 17.6 kilowatt hours per kilogram of aluminum (kWh/kg Al) by dividing average annual smelter energy use by annual aluminum output. To account for production levels below 100%, we scaled average annual energy use by using the plant's capacity factor (actual production divided by nameplate capacity). We compared our results to the range of energy intensities reported by the International Aluminum Institute in 2007 (IAI 2007, the most recent data source available at the time of modeling). The Institute reported a range of energy intensities of 13.5 to 19.3 kWh per kg of aluminum ingot, bounding all of the intensities estimated in our study. Koffler and colleagues' suggestion that we employ measured smelter data is at odds with the fact that, as they state in their letter, "…the exact power intensity of smelting is confidential operational information" and hence unavailable.

When discussing the emission factor of Warrick's on-site coal-fired power plant, Koffler and colleagues discuss the average emission factor of the 401 coal-fired power plants in the U.S. However, there is no need to compare our value to the U.S. average as all the data are available and the process is straightforward. Warrick's reported at-plant emission factor was provided in eGrid 2012 as 1.34 kilograms of carbon dioxide equivalent per kilowatt hour (kg CO_2-eq/kWh) (U.S. EPA 2012). We find the statement by Koffler and colleagues that the emission factor at Warrick is 30% lower than we reported to only be possible if an electricity intensity of approximately 11.5 kWh/kg Al is used (including full fuel cycle emissions). An intensity of at least 12.6 kWh/kg Al would be required if only site electricity emissions were used. Both of these intensity values are appreciably lower than the average of 14.9 to 15.1 kWh/kg Al reported by Koffler and colleagues.

As a check on our U.S. emission factor for aluminum production, we used it to calculate a North American average to compare with Koffler and colleagues' value. Using U.S. and Canadian production data from the 2010 USGS Minerals Yearbook for aluminum, an estimated emission factor of 4.9 kg CO_2-eq /kg Al for Canadian aluminum (assuming 100% hydro and renewable electricity sources), and our emission factor of 19.9 kg CO_2-eq /kg Al for U.S. aluminum, we calculate a production-weighted North American emission factor of 10.4 kg CO_2-eq /kg Al, compared to the 8.9 kg CO_2-eq /kg Al reported by Koffler and colleagues. Data and sources for this calculation are provided in Table 1.

Recommendation

Our recommendation for researchers in need of an emission factor for primary aluminum is to use the publicly available and open source GREET database maintained by Argonne National Laboratory (greet.anl.gov). In the 2015 release of the GREET Life Cycle Analysis model, the Aluminum Association's 2013 report was used to determine a North American GHG emissions factor for aluminum production. A U.S.-specific aluminum smelter mix electricity emissions factor is also available in GREET, but the North American factor is provided as the default. The North American emissions factor associated with virgin wrought aluminum is 8.9 kg CO_2-eq /kg, while the U.S. smelter mix emissions factor associated with wrought aluminum is 13.4 kg CO_2-eq /kg. The electricity mixes for both scenarios are shown in Table 2.

It should be noted that that GREET's U.S. smelter mix is based on 2013 data. If 2010 data are used instead (Dai et al. 2015), the resultant emission factor is 17.9 kg CO_2-eq /kg. This can be compared with the 19.9 kg CO_2-eq /kg Al emission factor from our study for U.S. aluminum production based on plants operating in 2010; our higher emission factor reflects an electricity mix with more fossil fuels. Differences may be explained by how the fuel mix for plants was estimated; GREET relied on the Aluminum Association's self-reported values and our study used publicly available data with the nested average allocation method.

It should also be noted that our study determined smelter electricity emissions using actual emission factors from power plants in the same PCA and NERC regions that contain each smelter, while GREET uses U.S. average emission factors (by fuel type) for estimating electricity consumption emissions. It is unclear why the coal contribution based on the Aluminum Association values decreased so significantly in 2013 relative to 2010. Accounting for the closure of the Hannibal facility does not by itself explain the magnitude of the reduction. Due to the proprietary nature of the Association's member's reports, this decrease cannot be fully explored here.

We are happy to have had this opportunity to further explain our method and results and engage in this discussion. We feel this debate has highlighted the importance of transparency in the data and methods used in order to achieve at least objectivity, if not consensus, in LCA results.

Table 1. Calculated North American Primary Aluminum Production GHG Emission Factor

Metric	Value	Unit	Source
U.S. Primary Aluminum Production - 2010	1,726.00	1,000 mt	Bray and colleagues (2011)
U.S. Primary Aluminum Production Emission Factor	19.90	kg CO_2-eq /kg Al	Colett and colleagues (2015)
Canadian Primary Aluminum Production - 2010	2,963.00	1,000 mt	Bray and colleagues (2011)
Canadian Primary Aluminum Production Emission Factor	4.90	kg CO_2-eq /kg Al	Estimated from Colett and colleagues (2016) assuming 100% hydro and renewable electricity
Production Weighted North American Average Emission Factor	**10.42**	**kg CO_2-eq /kg Al**	**Calculated**

Table 2. Fuel mix for electricity in aluminum production scenarios detailed in GREET and using the Net Nested Average Allocation Protocol (Colett al. 2015).

Fuel Type	N.A. smelter mix	U.S. smelter mix - GREET 2013)	U.S. smelter mix - GREET 2010	U.S. Smelter Mix - 2010 from Colett et al. 2015(Net Nested Average)
Residual oil	0.0%	0.0%	0.0%	4.5%
Natural gas	4.1%	10.4%	1.3%	4.5%
Coal	14.3%	35.9%	65.2%	68.6%
Nuclear power	0.5%	1.4%	1.3%	3.1%
Biomass	0.0%	0.0%	0.0%	1.0%
Others (including hydro)	81.1%	52.3%	32.2%	18.3%

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(2015) assuming 100% hydro and renewable

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