Addressing uncertainty in life-cycle carbon intensity in the design of a national low-carbon fuel standard

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1. Introduction

This study examines how uncertainty can be accommodated in the design of a national low-carbon fuel standard (LCFS). An LCFS aims to reduce the carbon intensity (CI) of a region's transportation fuel mix by some target percentage by incentivizing low-carbon fuels. The CI for each fuel used is calculated using life-cycle assessment (LCA) methods so that upstream impacts of use are considered. Uncertainty is inherent in LCA due to data limitations and ambiguities, and general model uncertainty.

This work aims to answer the following: **How can an LCFS be improved to mitigate this uncertainty?**

2. Model Building, Monte Carlo Simulation

We model the life-cycle greenhouse gas emissions from gasoline and from ethanol with both corn and switchgrass as feedstocks.

The bio-fuel life-cycle stages considered are: Land use change; Feedstock production; Feedstock transportation; Fuel production; fuel distribution; and, Fuel combustion. The gasoline life-cycle stages considered are: Crude extraction; Crude transportation; Refining; Product transportation; and, fuel combustion. The functional unit for both pathways is 1 MJ fuel.

Monte Carlo simulation is use to evaluate the impacts of propagating uncertainty through a model. Parameter distributions are estimated based on data from published literature and government sources.

3. Simulation Results

The results of the Monte Carlo simulation are presented in Figure 1, and show a much higher distribution width for biofuels than for gasoline - 90 and 105 compared to 15 g CO₂e/MJ. Indirect land use change (ILUC) emissions is the major contributor to both the mean and the variance of the biofuels distributions, demonstrated by the impact of removing ILUC from the system boundary.

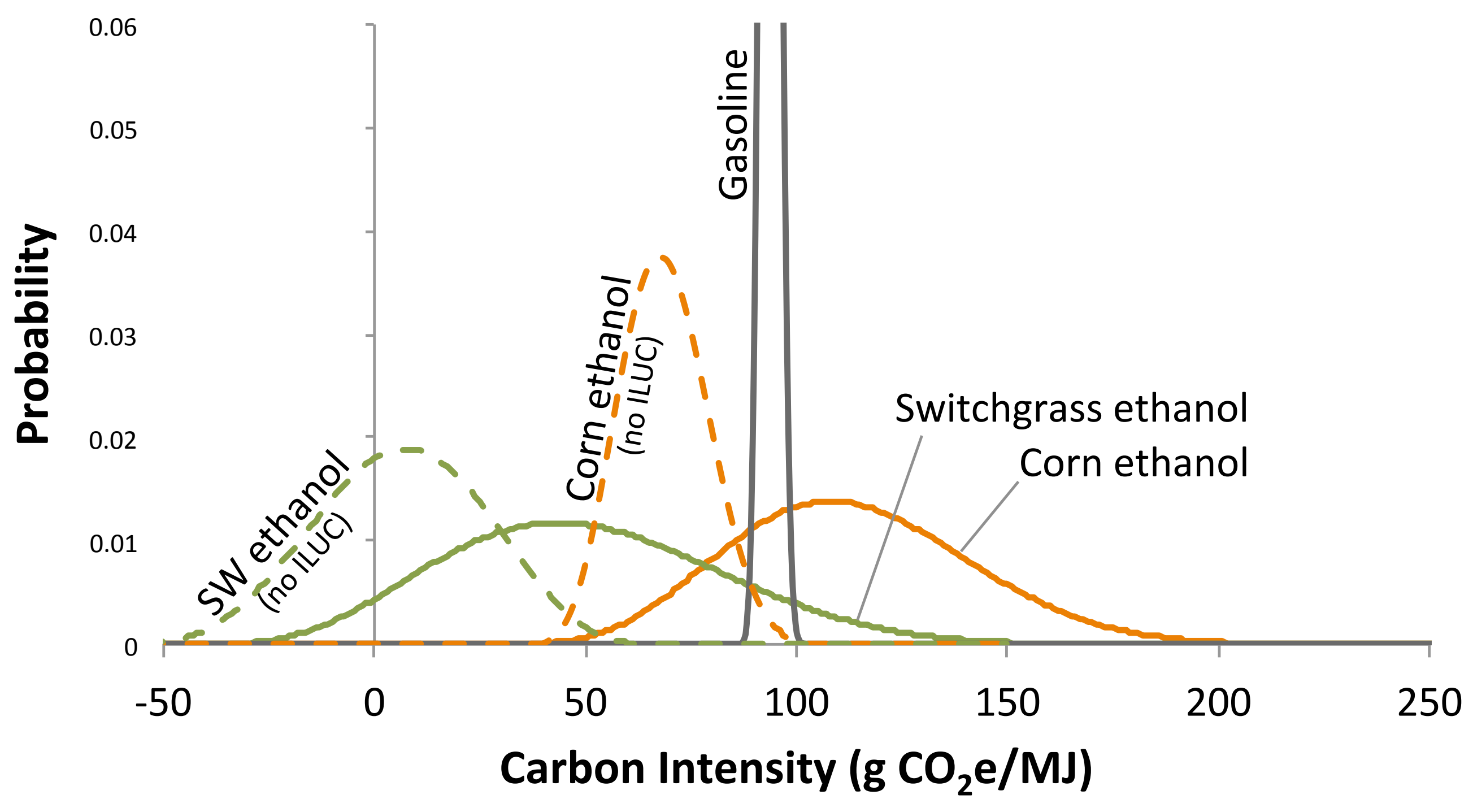


Figure 1. PDFs for emissions using national-scale data. Sources: (*1*, *2*)

4. Current Uncertainty Reduction Mechanisms

The current mechanisms built into policy to reduce uncertainty can generally be reduced to efforts to increase the quantity or the resolution of available data, and a commitment to update models as the system becomes better understood over time. This is meant to address some of the known sources of uncertainty, but there are uncertain parameters which cannot be resolved due to scientific uncertainty, not data limitations. Table 1 summarizes.

Table 1. Summary of uncertainty types and relevant model parameters.

Uncertainty Type	Reduction Mechanism	Fossil Fuel LCA Parameters	Biofuel LCA Parameters
Spatial or temporal variability	Opt-in reporting	• Crude extraction emissions • Refining energy use	• Hydrolysis efficiency • Production energy • Feedstock composition
Data limitations	Increased data reporting req'd	• Combustion emissions • Crude oil origin	• Feedstock yield • Nitrogen fertilizer application rate
Scientific uncertainty	Adaptive management	None modelled	• DLUC • ILUC • Nitrogen volatization

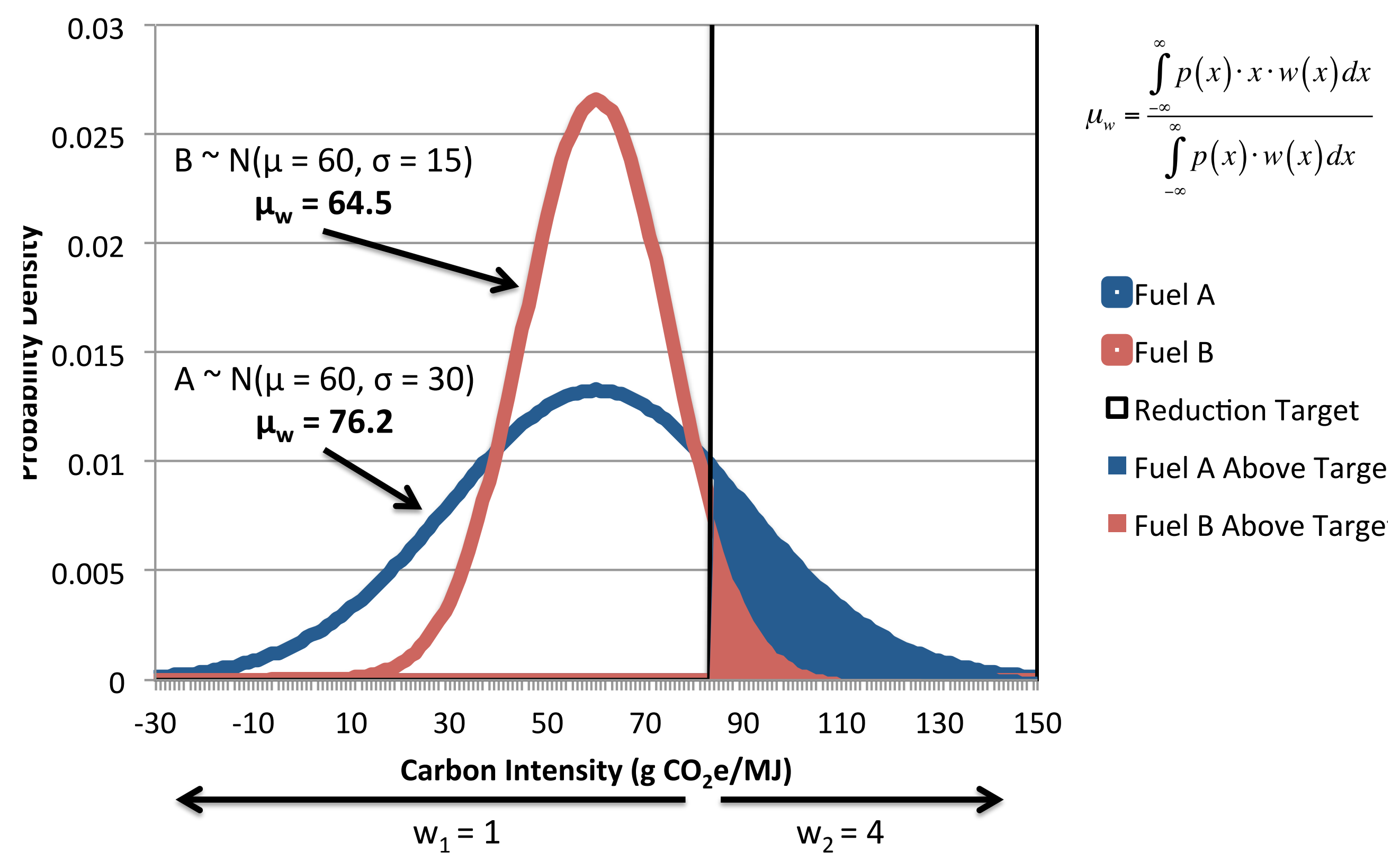
The question asked here is: How much can data reporting do to address uncertainty in emissions? We calculate 90% confidence interval widths for biofuels emissions, assuming each of the "knowable" parameters is fixed the distribution mean. Widths in Table 2 show that if all of the data which can be reported is, the decrease in distribution variance is minimal. This is due to the highly uncertain, and currently unknowable, land use and N₂O evolution parameters

Table 2. 90% confidence interval width (g CO₂e/MJ) under each scenario.

Fuel Type	Base Case	Opt-In	Opt-In + Data Reporting
Corn ethanol	89	87	80
Corn etOH (no ILUC)	40	38	36
Switchgrass ethanol	106	94	91
SW etOH (no ILUC)	59	35	34

5. Proposed Methods to Incorporate Uncertainty

We propose two methods to incorporate uncertainty. They can be used in parallel or separately. The first method is a different way to calculate a distribution mean. The idea is to penalize the portion of a distribution that lies above a reduction target value. In Figure 2, though both distributions have the same mean value, Fuel A is less certain than Fuel B, so Fuel B has a higher weighted mean value.



$$\mu_w = \frac{\int_{-\infty}^{\infty} p(x)\cdot x\cdot w(x)\,dx}{\int_{-\infty}^{\infty} p(x)\cdot w(x)\,dx}$$

Figure 2. Illustration of the target-weighted distribution mean. Source: (*3*)

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The second method calculates a probability of policy failure (i.e., probability that emissions are greater than the reduction target) by using an overall carbon intensity distribution, produced by sampling fuel-specific distributions proportional to the total energy provided by that fuel during some reporting period. This concept is illustrated in Figure 3, where four fuels are sampled to produce the total distribution. Calculating this probability of failure can inform how the fuels are incentivized during the next reporting period - if the probability is too high, fuels with lower means and/or smaller right tails can be made more valuable under the policy.

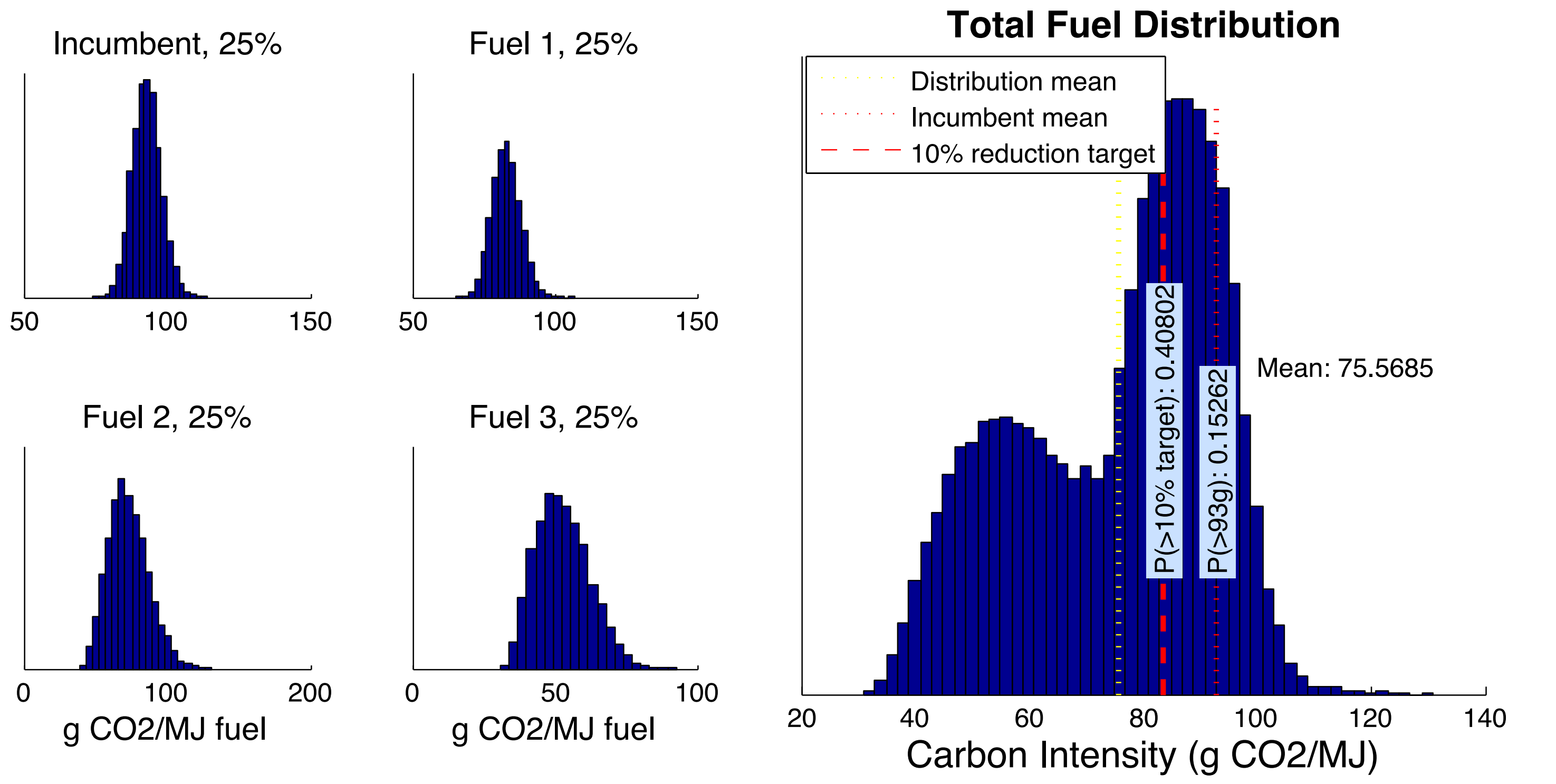

Figure 3. Illustration of the end-of-year total fuel consumption PDF. Source: (*3*)

6. Conclusions and Recommendations

The uncertainty for both gasoline and ethanol is large enough to make a 10% reduction target essentially meaningless. For biofuels, variance cannot be sufficiently decreased by simply requiring increased data reporting - too much uncertainty is due to land use change emissions and field-level N₂O formation, which are not currently well understood.

Policy should use the information contained in a distribution to inform the value of a fuel under an LCFS framework rather than just reducing all fuels to a mean value. We propose two potential methods to incorporate emissions distributions: calculating a weighted mean that penalizes long-tailed distributions, and calculating a volume-weighted total fuel distribution to examine the probability of LCFS policy failure.

7. References

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