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Clean Cookstoves Need Better Performance Guidelines

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Pollution from cooking fires is today's greatest environmental health risk factor— air pollution attributable to cooking causes some 3−4 million annual premature deaths.[1,2] Thus, many agencies have looked to "clean cookstoves" to help solve the crisis of cooking. However, despite the enormity of the problem, current standards for regulating cookstove performance are not mechanistically linked with the most important risk factor for health: how much pollutant enters the respiratory system. Today, two standards are instrumental for regulating safer levels of emissions from cookstoves: the World Health Organization's (WHO) Indoor Air Quality Guidelines and the International Standards Organization (ISO) International Workshop Agreement (IWA) (the new ISO/TC 285 standard is also currently in development). In an attempt to reduce the risks of cooking, both standards have provisions to regulate emission *rates* of cookstoves (mass of pollutant emitted per unit time). However, emissions rates of episodic sources are not causally linked with health outcomes; instead, total emissions should be regulated. Although the difference seems subtle, regulating emission rates rather than total emissions is misguided and could establish perverse incentives to design more harmful cookstoves.

Respiratory intake and uptake, or the amount of pollutant entering and depositing in the respiratory track, respectively, are suspected to be the primary drivers of disease. Both the WHO and ISO/IWA systems' guidelines for cookstove emission rates fall short because emission rates are not mechanistically linked with respiratory intake or uptake. Authors of the current standards sought to control emission rates as a means of controlling indoor pollution concentrations.[3] However, while emission rate and indoor concentration are mechanistically linked, indoor concentrations from episodic sourcese are not meaningfully linked with respiratory intake or uptake.[4] The implicit assumption of today's standards is that a cookstove with lower emission rates will lead to lower indoor concentrations of pollutants and will therefore be safer for the user. However, this assumption is not necessarily true.

The conflation of indoor concentration and emission rate with exposure may be due to historical regulation of emission rate for certain always-on indoor sources (e.g. a leaky indoor heating stove). For sources with close to 100% duty cycle (the "active" proportion of time), indoor concentration is indeed mechanistically linked with respiratory intake, and emission rate is a good proxy for exposure. However, cookstoves have low duty cycle—for most of the day they are not generating any emissions—and must be regulated differently. The "well-mixed box model" is a common tool used to estimate exposure and intake (in fact, a box model was used by WHO to calculate emission rate targets). We can solve a simple box model of a rural kitchen to reveal respiratory intake, I, is proportional only to the total mass of emissions, M, and the ratio of the occupant's volumetric respiration rate, Q_b, to the ventilation rate of the room, Q. When it comes to pollutant intake, the only variable cookstove designers can control is total emissions, M.

$$I = M\frac{Q_b}{Q} \tag{1}$$

In Monte Carlo analysis that informed the WHO metrics, there was a simple probabilistic model of cooking duration and cooking events per day that potentially led to conflation of emissions rate and emission exposure. In a simplified cooking model, one might assume 1 hour of cooking per meal and three meals per day. If cooking duration and number of meals remained unchanged with a new cookstove, average emissions rate and total emissions would be linearly related by total daily cooking time, t (i.e. $M = \dot{E}t$). However, this assumption is unlikely to hold as next-generation cookstoves are built under a new emission rate-based guideline system.

Presumably, emissions rate standards will setup a powerful incentive system to design stoves with low emissions rates. Because, all else equal, emissions rate is a linear function of firepower, an incentive to reduce emissions rate will also create a perverse incentive to decrease cookstoves' firepower. If emissions rate is the metric by which cookstoves' merits are measured, it is much easier to decrease the rate of fuel consumption (firepower) than it is to engineer fundamentally cleaner cookstoves with lower emissions factors (ratio of

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emissions mass to fuel mass). Firepower and time to boil (a proxy for cooking time) have an inverse power relationship,[5] and at low firepowers, halving firepower more than doubles cooking time. This is because the longer a pot sits on a cookstove, the more heat the pot will lose to its surroundings.

If cookstove guidelines incentivize lower firepower (as a "cheap" way to score better without improving combustion processes), cooking times will scale faster than emissions rates decrease, total emissions will increase, and respiratory intake will be higher. This concept is illustrated in Figure 1. Today, a

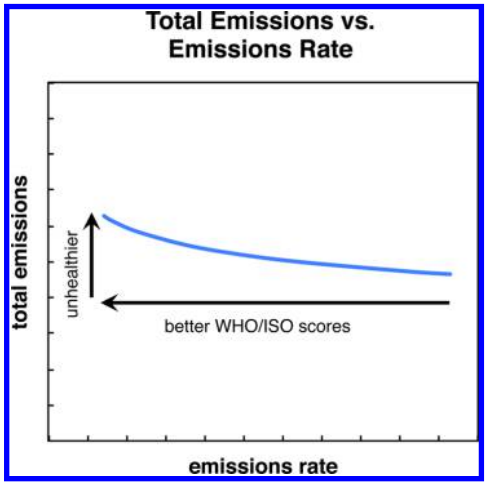

Figure 1. Cooking the same meal at decreasing firepowers on the same cookstove results in better WHO and ISO scores and unhealthier outcomes for the cook.

cookstove that emits 2 mg/min of $PM_{2.5}$ (fine aerosol emissions deleterious to health) over 60 min of cooking (M = 120 mg) will outrank a cookstove that emits 3 mg/min but only takes 30 min to perform the same job (M = 90 mg). In other words, current standards could be creating a perverse incentive to design more harmful cookstoves. Depending on the baseline cookstoves being replaced, "upgrading" cookstoves under these guidelines could increase cooking-related deaths.

One criticism of this argument is that reducing cookstove firepower to game emissions guidelines is impractical and therefore unlikely. For example, if firepower is too low, the cookstove won't be desirable to customers and the market will self-regulate; it would be comically impractical to try reducing emissions rate 10-fold by making a 10-fold smaller mini cookstove. However, cookstoves are ranked on a "4-Tier" system with hard cutoffs for performance tiers. If a cookstove designer is 10% away from achieving a better tier of performance, reducing cookstove size and firepower would be low-hanging fruit to "improve" emissions while creating higher respiratory intake and a less useful and desirable cookstove.

More effective performance guidelines and emission tier targets should focus on total emissions per useful cooking task completed. For example, the current ISO/IWA has a system for ranking cookstove emissions based on the total emissions per energy delivered to the pot (however, this ranking is only for "high power" cooking when water is being brought to a boil). Because emissions per useful cooking task is tightly linked with health outcomes and is difficult to game, it should be applied more generally throughout current and future standards.

This analysis shows that the current standards for evaluating cookstove performance fall short of promoting healthier cookstoves. Although indoor concentration of pollutants is reduced by lowering emission rate, total intake is not necessarily affected, and may increase. Lower indoor emission rates can improve acute symptoms of exposure such as burning eyes, coughing, and acute carbon monoxide poisoning, but acute symptoms are not the problem most regulators are trying to affect. Evaluating cookstoves based on mass emissions rates may only provide a perverse incentive to create low-power cookstoves that emit pollutants slowly, take longer to cook, and emit more overall. As ISO/TC 285 and WHO work to improve cookstove performance guidelines and emission tier targets, it is important to consider total mass of pollutant emitted per useful output (e.g., per meal or per energy delivered) as the most important factor for improving long-term health.

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Notes

The author declares no competing financial interest.

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