NORM ROAST

A Protocol to Compare Energy Efficiency in Roasting Machines

By Marko Luther and Dave Baxter

CONSUMPTION AND EMISSION protocols for all types of machinery, including cars and major appliances, have existed for quite a while. In coffee roasting, however, there has been no defined standard that allows us to compare the energy consumption and the release of pollutants of different machines across manufacturers.

Optimizing energy efficiency in roasting equipment is critical to reducing the harmful effects of climate change and to keeping a roasting company's costs down, but selecting a roasting machine based on energy efficiency or CO_2 emissions is currently close to impossible. The technical documentation of a machine usually includes the rating of the heating source, but only in some cases is energy consumption provided. In rare cases, the electric consumption of the motors and other components will be included. Emission values are even harder to come by. A lack of information about the conditions under which consumption and emission figures apply makes it impossible to estimate how much energy is actually needed to roast a kilogram of green coffee on a given machine and with the intended roast result.

NORM ROAST, a new project spearheaded by a consortium of roasting machine manufacturers and field experts, aims to change that by developing a standard protocol to measure energy usage and CO_2 emissions in small to medium-sized roasting machines.

A LACK OF COMPARABLE DATA

Currently, the efficiency of one roaster model cannot be compared to another using the heating system rating and batch size advertised by the vendor, and it is rare to find any objective information on emissions. As part of our research for this article, we surveyed the published burner ratings of over 700 models of roasters from 150 manufacturers. Many manufacturers do not publish burner ratings, while others provide ratings that are not plausible. To account for this, we removed unrealistic or incomplete ratings from the data set, reducing the data points by about half.

Figure 1 (page 34) presents these burner ratings plotted against roaster capacity. Each point represents an individual roaster model. There is a notably wide spread of burner ratings found for any given capacity. The shaded area encompasses a range of burner ratings where the upper value is four times larger than the lower value. This highlights the huge spread of published burner ratings from one roaster model to another with the same capacity. This could indicate that either the method of determining the burner rating varies widely, or that the efficiency of the roasters varies greatly, or even that the burner design is not matched to the roaster capacity. Any of these explanations raises a warning flag that a better comparison of roaster efficiency is required.

FIGURE 1.
NOMINAL BATCH SIZES VS BURNER RATINGS

BEYOND SIMPLE EFFICIENCY

To limit the effects of climate change, CO_2 emissions must be reduced in all sectors, including coffee production and consumption. According to an article titled "Carbon Footprint across the Coffee Supply Chain: The Case of Costa Rican Coffee," published in the *Journal of Agricultural Science and Technology* in 2013, the total carbon footprint across the entire coffee supply chain is about 4.82 kilos of CO_2 per kilo of green coffee. Technically this classifies coffee—a nonessential commodity for human life—as a high-intensity source of emissions. Another study, published in 2008 by the German PCF Pilotprojekt Deutschland (case study on Tchibo GmbH), found that roasting contributes 1.62 grams of CO_2 per cup of coffee produced. These studies support a total of about 2 million metric tons of CO_2 emitted to roast the 168.71 million 60-kilo bags the International Coffee Organization reported were consumed on this planet in 2020. Clearly, there is the need to reduce emissions connected with the roasting process.

CO_2 emissions are tightly coupled with overall energy consumption, as well as the type of energy used, thus reducing total consumption and shifting to renewable energy can help reduce these harmful emissions. Other options to achieve reductions are process optimizations and technology advances that allow replacing critical processes with more energy efficient ones. In coffee roasting, there are two main factors that determine the total CO_2 amount emitted to produce a certain amount of roasted coffee:

- The roasting process itself, defined by factors like the preheat process, the final roasting degree, and the total roasting time.
- The roasting technology applied, like the heating source (see Figure 2, page 36) and the energy efficiency of the roasting machine.

FIGURE 2 | CO_2 EMISSIONS BY ENERGY SOURCE

Energy Source	CO_2 Emitted	Reference
Propane	214.56 g/kWh	[1]
NG	180.54 g/kWh	[1]
Electricity	385.55 g/kWh	[2]

[1] U.S. Energy Information Administration. "Carbon Dioxide Emissions Coefficients." EIA Environment, *https://www.eia.gov/environment/emissions/co2_vol_mass.php*. Accessed 02 January 2021.

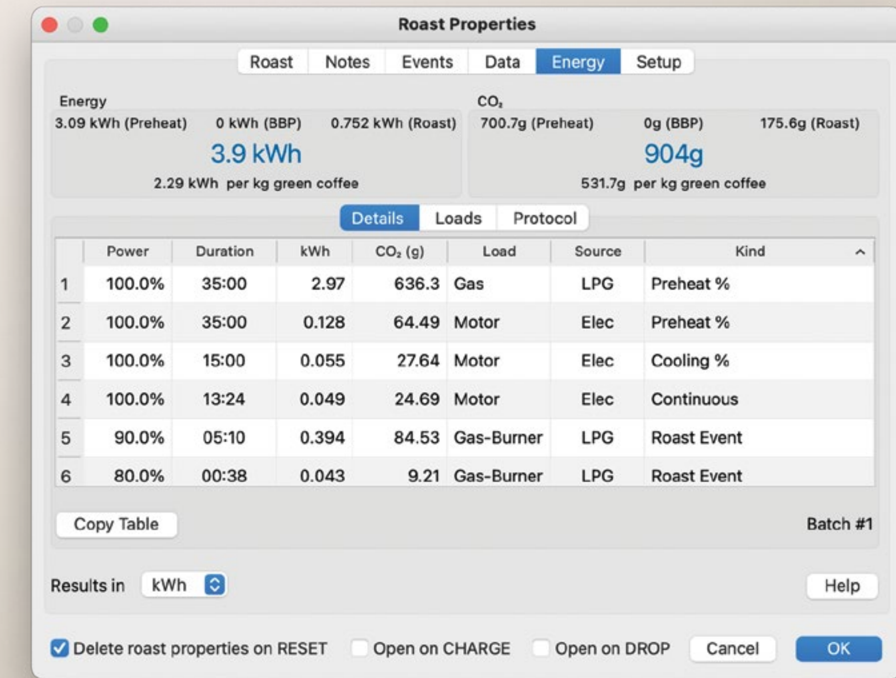
[2] U.S. Energy Information Administration. "How much carbon dioxide is produced per kilowatthour of U.S. electricity generation?" EIA Frequently Asked Questions, *https://www.eia.gov/tools/faqs/faq.php?id=74&t=11*. Accessed 2 January 2022.

Tools are needed to quantify the effect of variations in the roasting technology. It is utterly unhelpful to read that a certain machine has a "50 percent better fuel economy" if it remains unclear under which conditions and compared to what. Opportunities to optimize the roasting process are usually limited because product quality should not be compromised. Energy consumption can be reduced by changing the airflow with the disadvantage of increasing smoke build-up in the drum, or by maximizing the batch size for a better energy-per-kilogram ratio with the risk of losing control of the profile. Still, increasing the number of batches per session or optimizing the protocol applied between batches can help to reduce emissions. But machine design has far more impact on energy efficiency than mere process changes and applies universally to all roasts.

The Energy Calculator, included in the open-source roasting app Artisan, is one tool that allows roasters to approximate energy use and CO_2 production per roasted batch. The *artisan.plus* inventory management platform uses machine parameters and the actual roasting profile to compute the total energy, total CO_2 footprint, and the average CO_2 emitted per kilogram of roasted coffee over a given period of time (see Figure 3, page 38). This information can be used to observe, reduce and offset a company's CO_2 production to make it carbon neutral. However, this tool fails to compare the efficiency of the applied roasting technology as the process itself is not a constant.

To compare the efficiency of different roasting technologies, machines have to be tested in a reproducible way. All parameters that might have an effect on the energy consumption must be kept constant except for the machinery itself. We propose a set of standardized conditions to measure energy consumption, CO_2 emissions and pollutant emissions from roasting machines, very much like the European Union's Worldwide Harmonised Light Vehicle Test Procedure (WLTP; *wltpfacts.eu*), which measures fuel consumption and CO_2 emissions for passenger cars.

FIGURE 3 | ARTISAN ENERGY CALCULATOR



MEASURING ENERGY CONSUMPTION AND EMISSIONS

In summer 2021, a number of roasting machine manufacturers and other experts formed the open NORM ROAST consortium (*norm-roast.org*) to develop a standard protocol to measure the energy consumption and emissions of small to medium-sized roasting machines. As a first step, the following requirements were formulated.

The protocol should make the efficiency and emissions of roasting machines comparable. It should be universally applicable, and it should cover all consumption and emissions involved in roasting, including the ones contributed by operating electrical motors and electronics. Most importantly, the results should be relevant, and should translate to consumption and emissions in standard machine operation and thus relate directly to the efficiency of a machine type as it is specified and sold. It should be relatively simple for independent entities to run the protocol and verify the results. The protocol must be fully defined in all relevant aspects and allow for good documentation.

A number of complications were identified that make it challenging to find a process able to fulfill all of these requirements. We will discuss those in the following sections, together with the solutions identified for the NORM ROAST protocol.

The Setup

To ensure that NORM ROAST results are comparable, the evaluation process has to be followed strictly and all other conditions that might influence the results must be equal. To address this, NORM ROAST standardized the environmental conditions in a range that should be possible to meet in most parts of the world, requiring the ambient temperature to be in the range of 20 to 30 degrees C (68 to 86 degrees F) and air pressure to be within 1050 to 9500 Hectopascals (hPa), the international unit for measuring atmospheric or barometric pressure.

The Beans

Evaluating empty machines will not lead to relevant results. Thus, NORM ROAST tests have to be conducted while roasting with beans in the roaster. The energy consumption of a roast depends on the type of beans and their condition. Species, processing, density, size, moisture content and temperature all influence roast energy consumption. NORM ROAST requires using a washed arabica with a moisture content of 10.5 to 11.5 percent, a bulk density of 670 to 730 grams per liter and a screen size of 17 to 18.

The Batch Size

While the energy consumption of a roast depends on its batch size, fixing the batch size to a specific value will not allow for comparing machines of different sizes. The mismatch between heater ratings and nominal batch sizes, as promoted by machine vendors, does not provide a consistent indicator. Therefore, NORM ROAST does not dictate the batch size. To achieve minimum consumption with a given machine under NORM ROAST conditions, one needs to choose a suitable batch size and optimize the other machine parameters that influence consumption. Heater output, air flow settings and drum speed are adjusted such that the test profile meets the required time. Of course, activities that may increase the energy consumption—like taking samples during the test roast with the trier, which allows cold air to enter the drum—must be avoided during testing.

The Cycle

The thermal state of the roasting machine before starting a roast strongly influences the additional energy that has to be added during the roast to follow

a certain profile. Therefore, the NORM ROAST test cycle spans the full process, including the preheating of the machine and four back-to-back roasts, along with their between-batch processes.

The Profile

To ensure that the energy consumption is comparable, the produced roasts must be consistent. One could define the roast target by weight loss or the moisture level of the roasted beans. However, weight loss only weakly correlates with energy consumption, which also depends on airflow and organic matters. Conventional conductive moisture meters have low accuracy on the lower moisture concentrations of roasted beans. Roast color could be a criterion, but it also turns out to be a fragile measurement. To date, there is no well-defined standard roast color scale available that could ensure verifiable results. Furthermore, a study titled "Roasting Conditions and Coffee Flavor: A Multi-Study Empirical Investigation," published in *Beverages* in 2020, showed that the same target color can be achieved by roasting profiles of varying length on the same machine using the same beans, where each of those roasts might consume a different amount of energy. Roasted weight, moisture and interior color cannot be verified during roasting, which makes them impractical as guidelines for the test roasts as well.

The NORM ROAST protocol ensures comparable roast results by requiring each of the four compulsory roasts to follow the same specific bean temperature profile. Each roast should enter first crack at 10:00 minutes into the roast and should end with a total roast time of 12:30 minutes. Mandating absolute temperature targets is not feasible as bean temperature readings depend on probe type and placement, and are also affected by airflow and other factors. For example, the bean temperature logged at first crack in a set of community data comprising 130,000 roasts, conducted on many different machines, averages 198 degrees C

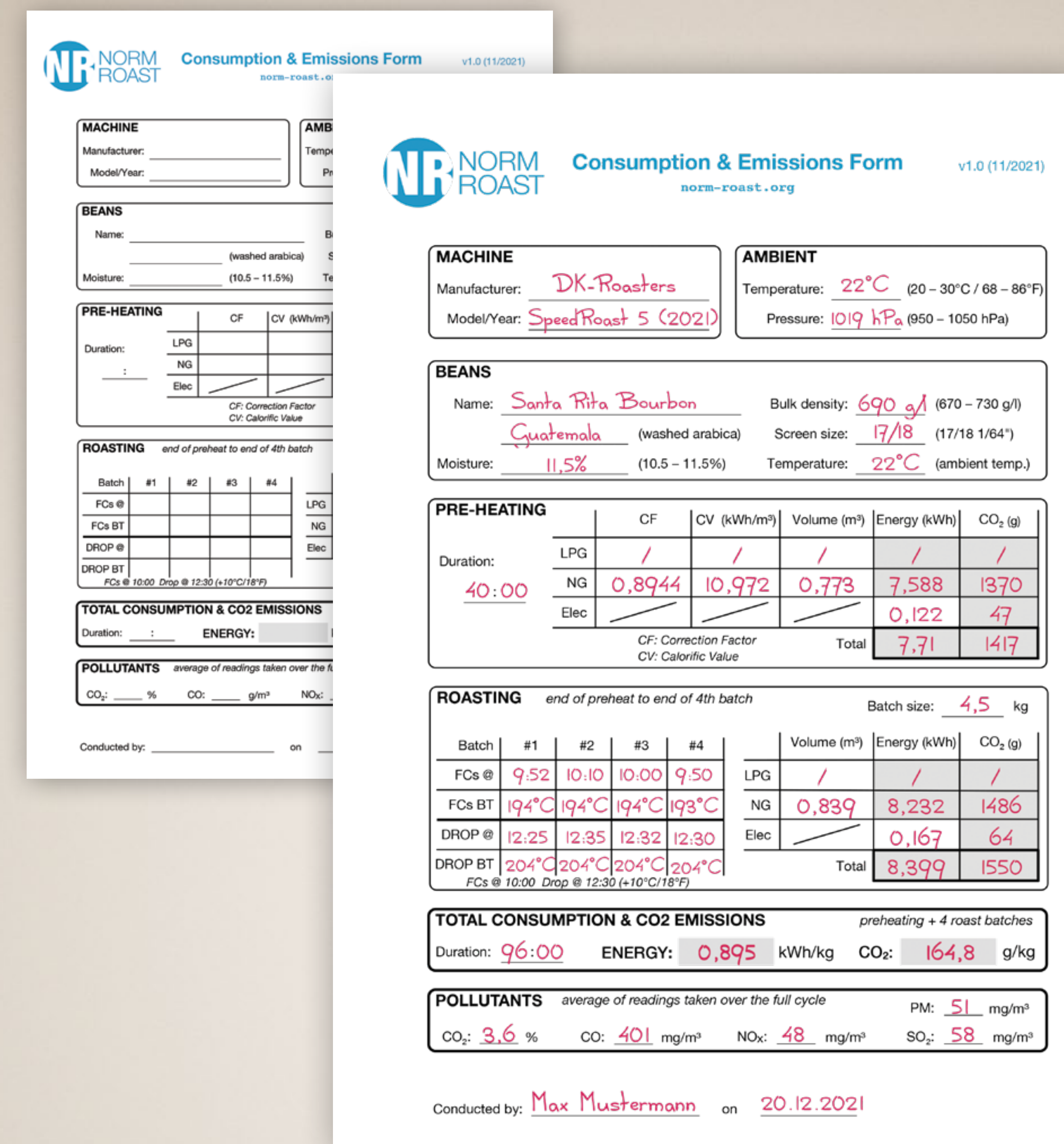
(388.4 degrees F) with a standard deviation of 7.6 degrees C (about 14 degrees F). To make the results less dependent on absolute temperature measurements, NORM ROAST requires the final bean temperature at the end of each roast to be 10 degrees C (18 degrees F) higher than the temperature at the start of first crack.

The Measurements

A number of measurements have to be taken throughout the NORM ROAST test cycle to document the process and to calculate the final consumption and emissions. Those measurements are relatively simple to collect. They include data identifying the machine being tested, the ambient test conditions, the test bean properties, the preheat duration, the measured first crack start and drop temperatures, and roasting times. The actual consumption is to be measured separately per energy type (propane gas, natural gas and electric energy) during the preheating and the roasting phases. Gas consumption is usually measured by volume and then converted to energy consumption by respecting its caloric value with a correction factor to adjust for differences in pressure or temperature per location. Electric energy consumption can be directly measured with a metering device. Unfortunately, a significant amount of electricity is still generated from sources that emit CO_2, hence there is a CO_2 emission calculated from the electric consumption. The CO_2 emissions are calculated separately for each energy type using standard formulas. The results are then summed together for the total CO_2 emissions.

All the measurement data can be entered into a simple one-page form provided by the NORM ROAST consortium (see Figure 4, page 43).

FIGURE 4 | EXAMPLE OF A NORM ROAST CONSUMPTION AND EMISSIONS FORM



NORM ROAST Consumption & Emissions Form v1.0 (11/2021)
norm-roast.org

MACHINE
Manufacturer: DK-Roasters
Model/Year: SpeedRoast 5 (2021)

AMBIENT
Temperature: 22°C (20 – 30°C / 68 – 86°F)
Pressure: 1019 hPa (950 – 1050 hPa)

BEANS
Name: Santa Rita Bourbon Guatemala (washed arabica)
Moisture: 11,5% (10.5 – 11.5%)
Bulk density: 690 g/l (670 – 730 g/l)
Screen size: 17/18 (17/18 1/64")
Temperature: 22°C (ambient temp.)

PRE-HEATING
Duration: 40:00

	CF	CV (kWh/m³)	Volume (m³)	Energy (kWh)	CO_2 (g)
LPG	/	/	/	/	/
NG	0,8944	10,972	0,773	7,588	1370
Elec				0,122	47
Total				7,71	1417

CF: Correction Factor
CV: Calorific Value

ROASTING *end of preheat to end of 4th batch*
Batch size: 4,5 kg

Batch	#1	#2	#3	#4
FCs @	9:52	10:10	10:00	9:50
FCs BT	194°C	194°C	194°C	193°C
DROP @	12:25	12:35	12:32	12:30
DROP BT	204°C	204°C	204°C	204°C

FCs @ 10:00 Drop @ 12:30 (+10°C/18°F)

	Volume (m³)	Energy (kWh)	CO_2 (g)
LPG	/	/	/
NG	0,839	8,232	1486
Elec		0,167	64
Total		8,399	1550

TOTAL CONSUMPTION & CO2 EMISSIONS *preheating + 4 roast batches*
Duration: 96:00 ENERGY: 0,895 kWh/kg CO_2: 164,8 g/kg

POLLUTANTS *average of readings taken over the full cycle*
CO_2: 3,6 % CO: 401 mg/m³ NOx: 48 mg/m³ PM: 51 mg/m³ SO_2: 58 mg/m³

Conducted by: Max Mustermann on 20.12.2021

The Emissions

The direct emissions of pollutants like carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2) and particulate matter (PM) in the roasting exhaust air have to be assessed along with the energy consumption. The operation of each roasting machine has to fulfill the emission requirements of the local authorities. Some machines show a higher consumption as they operate their heat sources at higher temperatures, with the advantage of achieving tight emissions requirements by construction. The lower consumption of other machines might be offset by additional energy consumption (and CO_2 emissions) for additional exhaust air treatment (e.g., by the application of an external afterburner).

ESTABLISHING A STANDARD FOR COMPARISON

The roasting industry must have a consistent and verifiable protocol for comparing energy efficiency and emissions across the spectrum of machine designs and manufacturers. The NORM ROAST standard aims to fill this need, allowing the collection of consistent and verifiable numbers to stand next to marketing slogans. And as an open standard, NORM ROAST can be improved and extended to meet future needs.

Acknowledgements

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