Pellet-fed gasifier stoves approach gas-stove like performance during in-home use in Rwanda

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Pellet-Fed Gasifier Stoves Approach Gas-Stove Like Performance during in-Home Use in Rwanda

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Inyenyeri: a focus on fuel, stove and household

Implementer: Inyenyeri, a Rwandan Social Enterprise

- Mimi Moto stoves and **locally-produced biomass fuel pellets**
- Innovative business model: **Pay/trade for pellets, get free stove**
- **Pellets compete with charcoal (purchased) and fuelwood (gathered)**
- Large **emphasis on customer service** and follow-up
- See Jagger and Das, 2018, *ESD* for more…

Stove: Mimi Moto

- Pellet-fed forced-draft cookstove
- Lab tests: ISO Tier-4 for emissions and efficiency measurements (CSU)

Location: Gisenyi, Rwanda (small city)

- Headquarters and pilot roll-out

INYENYERI
A Rwandan Social Benefit Company

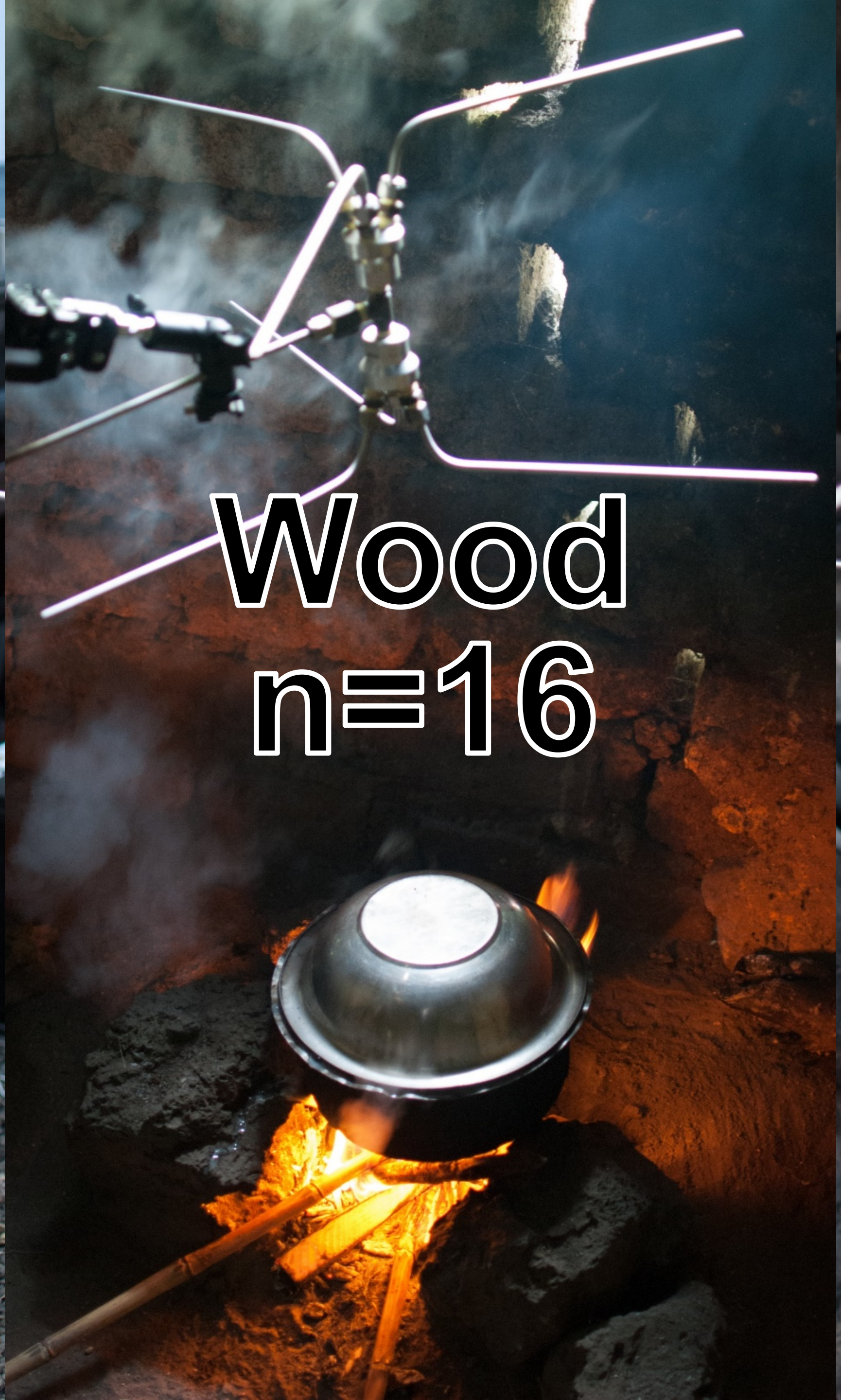
Photo: trendhunter.com

In-home measurements of Mimi Moto and baseline stoves

- ‘Randomized’ Household Selection
  - Pellet (~70% urban, ~30% rural)
  - Wood (100% rural)
  - Charcoal (100% urban)
  - 2 ‘seasons’, testing same households (Dec ‘17, May ‘18)
- Sampling Equipment
  - Stove Emission Measurement System (STEMS)
  - Plume-sampling probe
  - Real-time:
    - CO and CO_2
    - $PM_{2.5}$ Scattering and Absorption (Aethlabs µAeth)
  - Integrated $PM_{2.5}$ filter samples:
    - Mass, and Organic and Elemental Carbon (OC/EC)
- Carbon-balance method for emission factors
- Uncontrolled Cooking Test (UCT)
  - Participant cooks a meal of their choice with (ideally) minimal disruption

Mimi Moto and Sampling Equipment


Pellet
n=59
mimi moto
INYENYERI

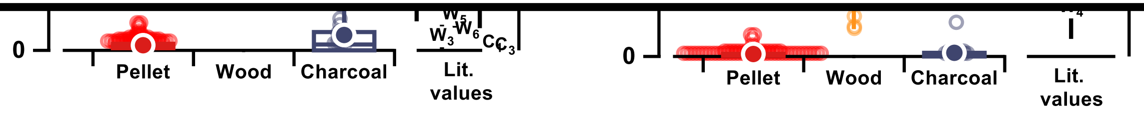

Wood
n=16


Charcoal
n=16

Pellet stoves reduce $PM_{2.5}$ emissions by 97% compared to Wood, and 89% compared to Charcoal

Mimi Moto medi … met' ISO T … in-use … issions

Compared to gasifier stoves with wood, field PM EFs are much lower (0.4 vs 2.5-4.1 g kg^{-1})



5. Global Alliance for Clean Cookstoves, 2018; 6. Garland et al., 2017; 7. Roden et al., 2009; 8. Coffey et al., 2017; 9. Wathore et al., 2017; 10. Rose Eilenberg et al., 2018; 11. Lefebvre 2016; 12. Grieshop et al., 2017

…and CO emissions by 87% compared to Wood, and 96% compared to Charcoal

Mimi Moto ‘met’ ISO Tier-5 for in-use CO emissions

EC emission factors and rates from pellet stoves are extremely low (99% reduction from wood)

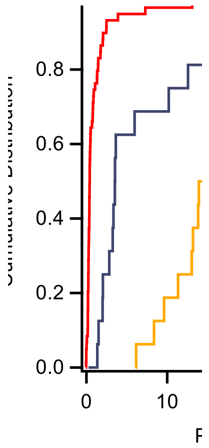
Pellet PM contains greater proportion of elemental carbon (EC) and are more light absorbing

$$SSA = \frac{\text{Scattering}}{\text{Extinction}}$$

EC/TC Ratio

Mimi Moto emits particles that are slightly more absorbing, but <u>much</u> less of them

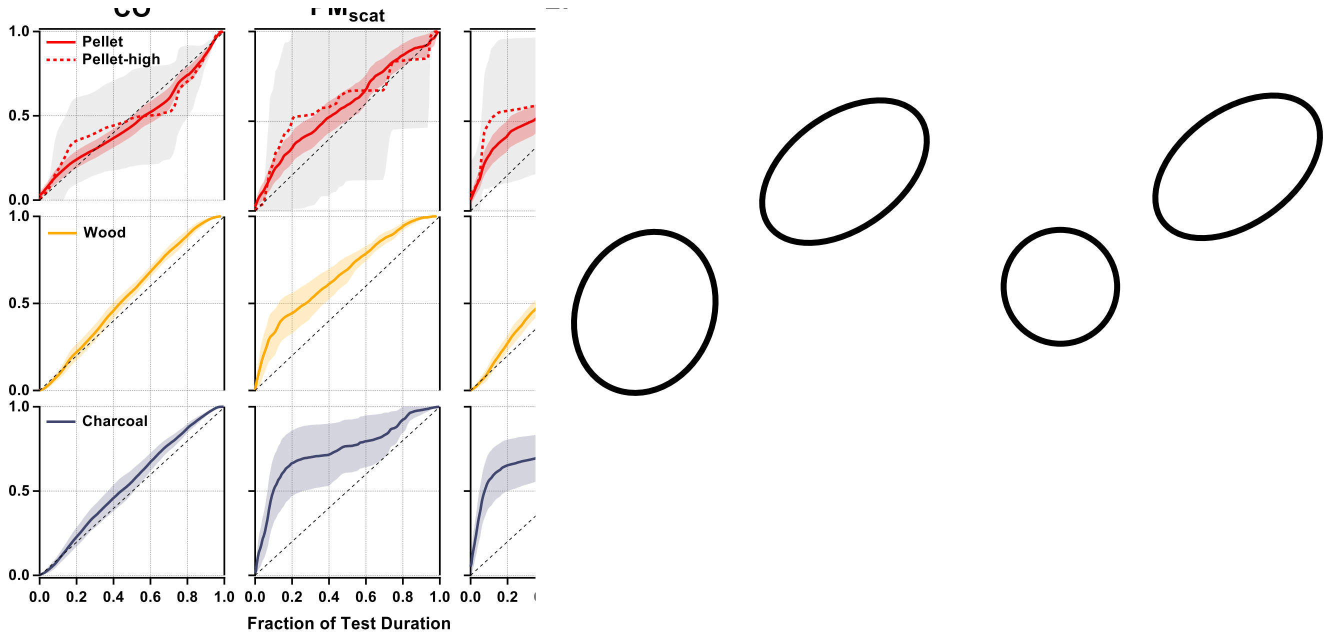
In general, pellet stoves work great, but not always!



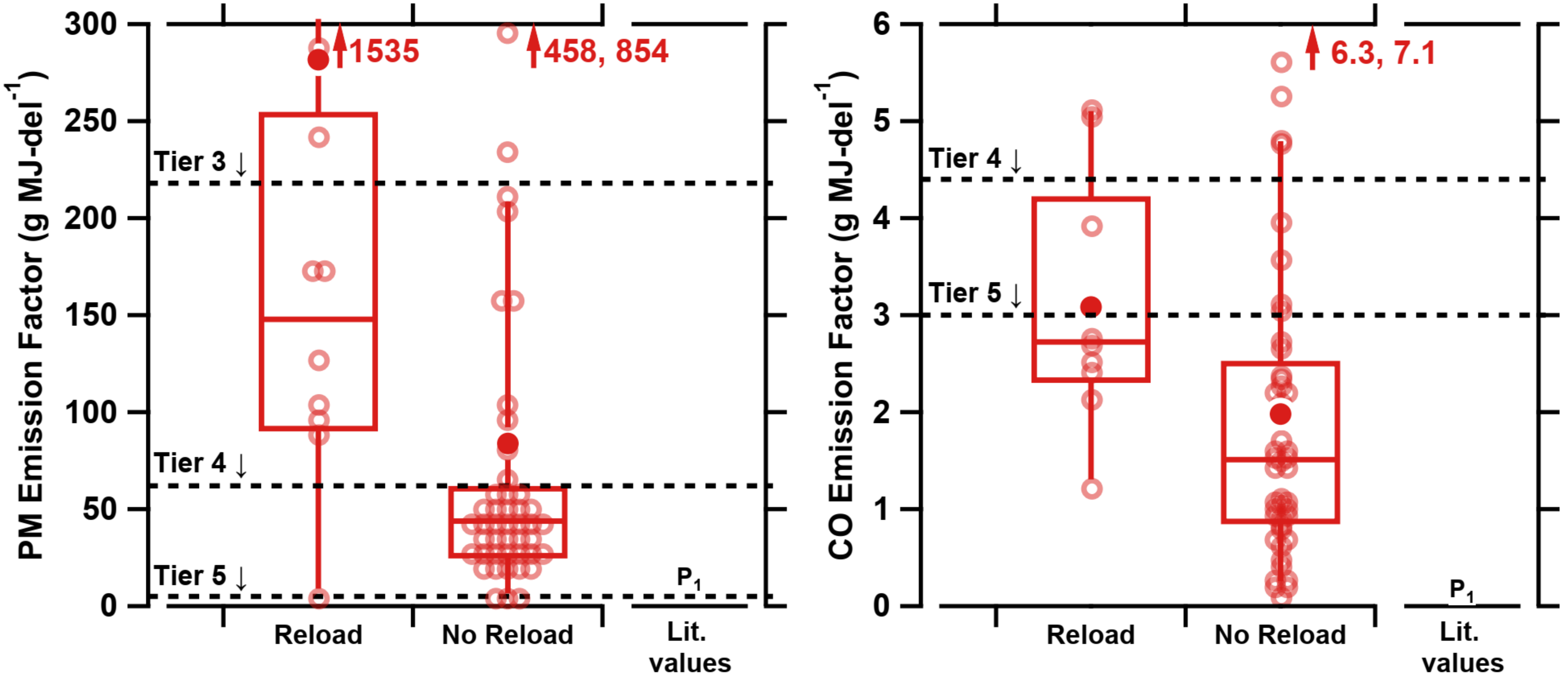
$PM_{2.5}$ EF Distribution

CO EF Distribution

During poor performance, pellet stoves emit in distinct events



Refueling associated with higher PM and CO emissions (also start-up and misoperation)



Pellet stoves: some indication of performance improvement over time

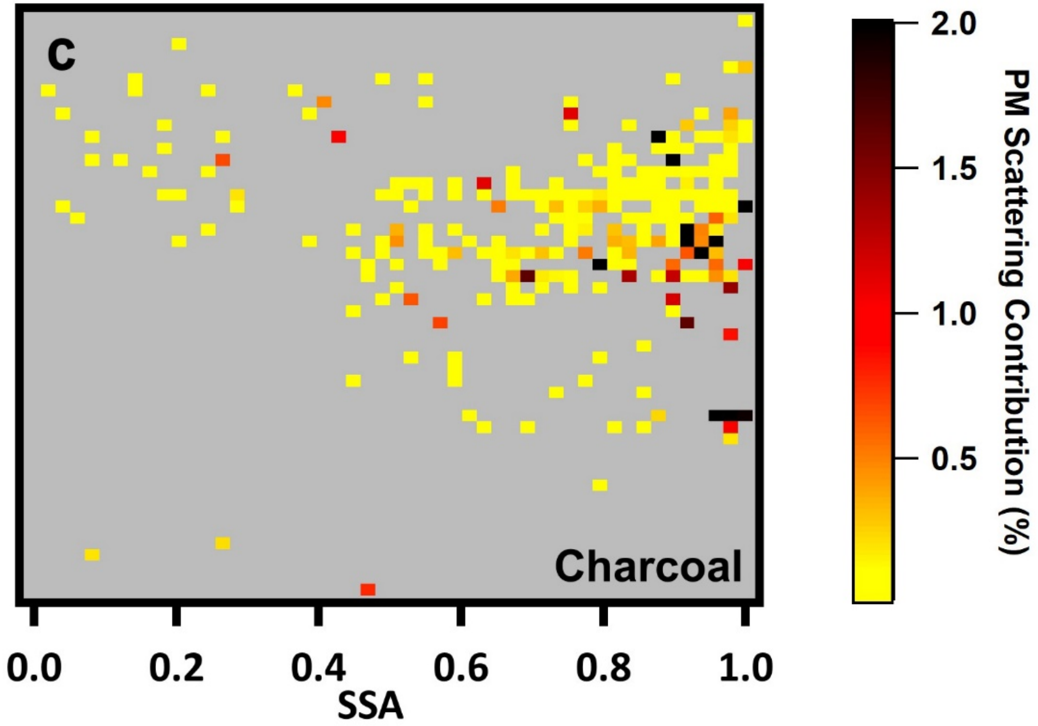
Patterns of Real-time Emissions Data (PaRTED)

2-D frequency plot
- Type of particle
- During what type of combustion event

$$MCE = \frac{CO_2}{(CO+CO_2)}$$

$$SSA = \frac{\text{Scattering}}{\text{Extinction}}$$

Increasing Efficiency

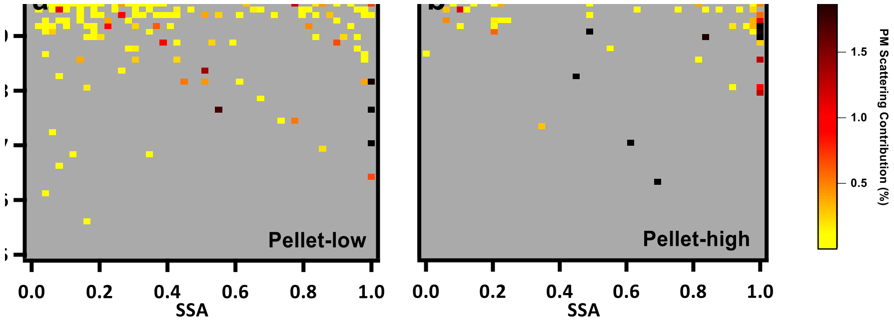


Light Absorbing

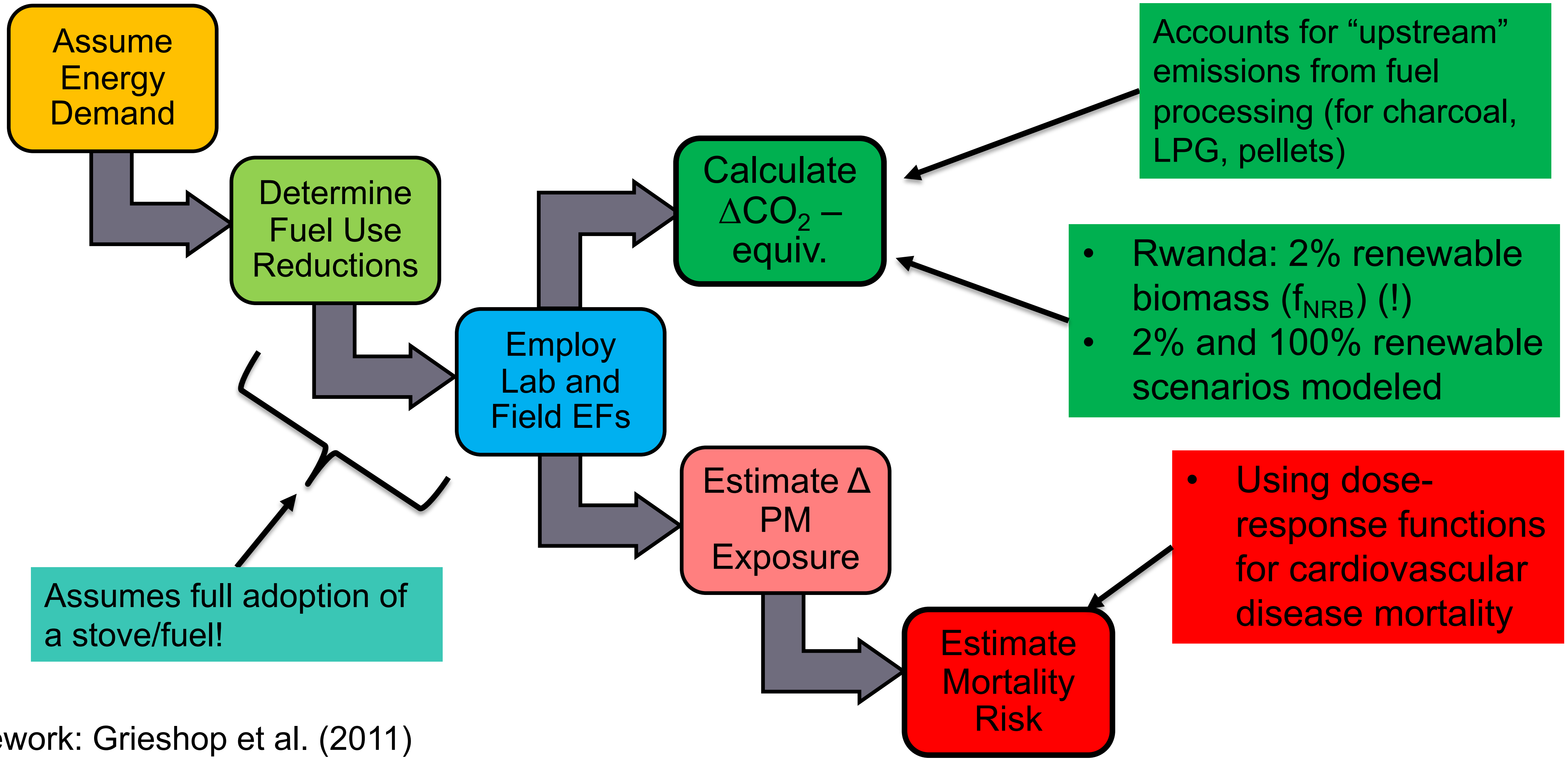
Light Scattering

13. Chen et al., 2012

Remember, Pellet stoves have generally lower SSA… Pellet-high stoves emit primarily high SSA PM

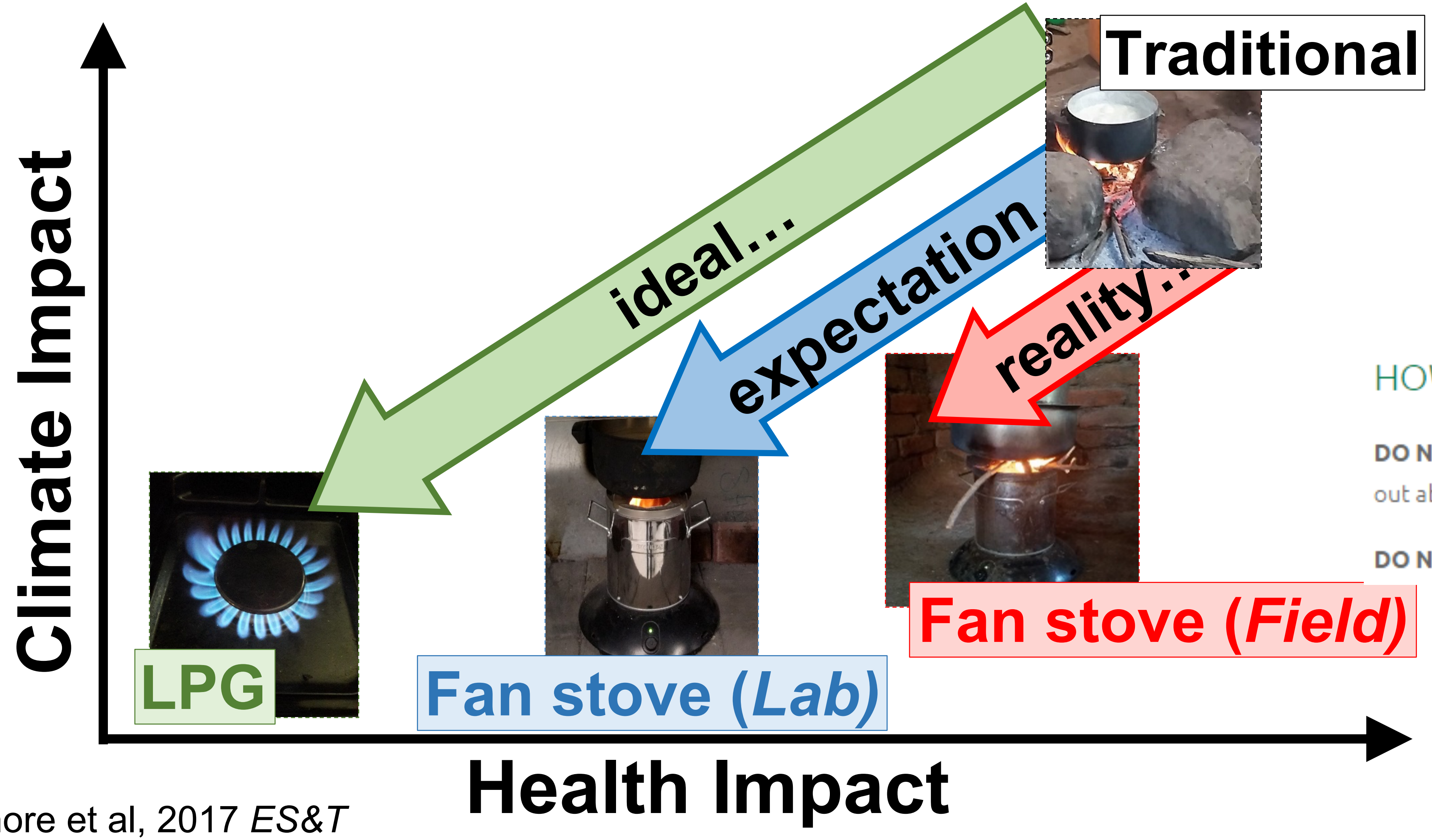


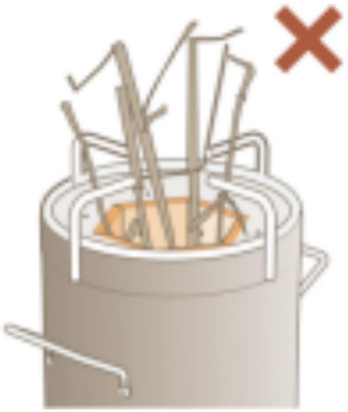
Apply a framework to estimate *potential* climate and health impacts and (co)benefits from stove options



Framework: Grieshop et al. (2011)

Ultra-low cooking emissions required for health and climate benefits, but not seen in ‘real-world’ use of biomass stoves





HOW TO AVOID SMOKE

DO NOT use long pieces of wood that stick out above the burning chamber.

DO NOT fill the stove to the rim or above.

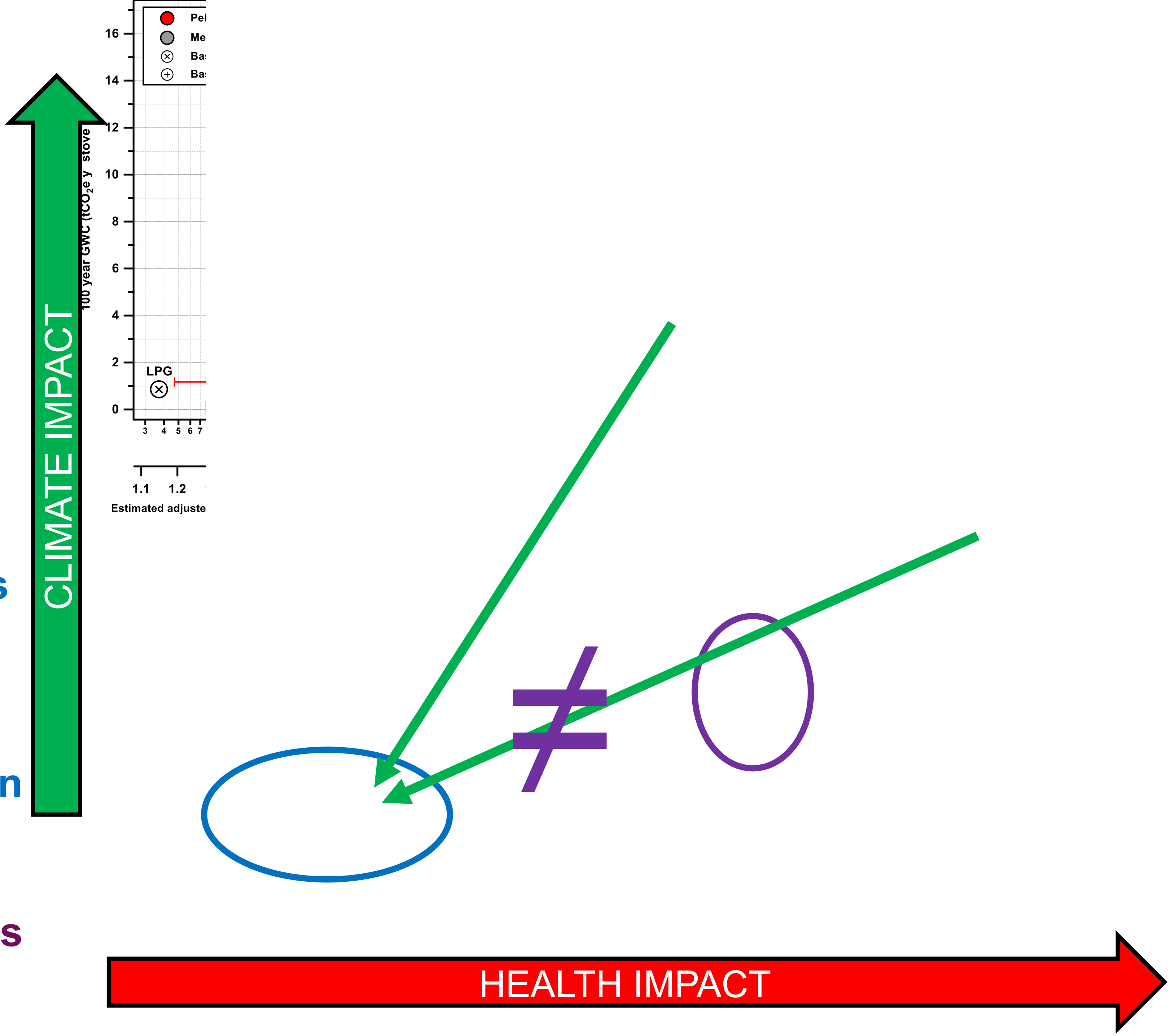
http://www.africancleanenergy.com/

Wathore et al, 2017 *ES&T*

Estimated pellet stove health and climate benefits *approach* LPG

Takeaways:

1) Huge potential co-benefits implied by field emission performance of pellet stove relative to traditional stoves/fuels.
2) Climate benefits match/surpass LPG, depending on feedstock renewability and energy for pellet production. Health impacts are slightly greater than LPG.
3) Use of pellets (homogenous fuel) leads to enormous benefits relative to gasifier with ‘gathered’ biomass.



In summary…

- **Significant** reductions of $PM_{2.5}$, EC, and CO emission factors and rates observed during in-home testing in Gisenyi, Rwanda
- Mimi Moto 'met' **Tier-4 for $PM_{2.5}$** and **Tier-5 for CO**
- However, ~10% of tests were "super-emitters", with emissions **on-par with traditional stoves types**
    - Dead stove battery, refueling, or kindling ignition
- During poor performance, pellet stoves emitted high PM and BC primarily following **ignition**, and near the end of test (**refueling/burnout**)
- Estimated health and climate **cobenefits of pellet stoves approach those from a modern fuel/stove (LPG)**

Thank you!
Questions?

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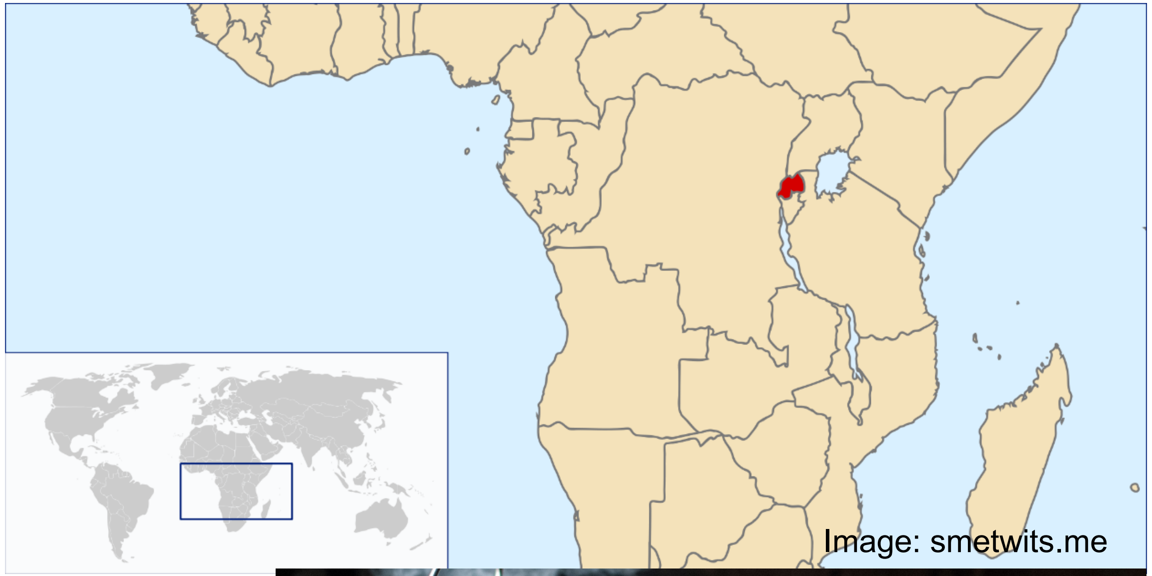
Web: go.ncsu.edu/grieshop_lab

Extra slides

Rwanda, the land of a thousand hills and a million smiles

- Located in East Africa
- Most densely populated nation on the continent
- 95% of population relies on solid biomass for cooking.[3]
  - Wood is dominant in rural
  - Wood and charcoal split in urban
- Lower respiratory infection is the leading cause of disability-adjusted life years lost (DALYs) in Rwanda[4].



3. Global Alliance for Clean Cookstoves, 2012; 4. Institute for Health Metrics and Evaluation, 2018

STove Emissions Measurement System (STEMS)

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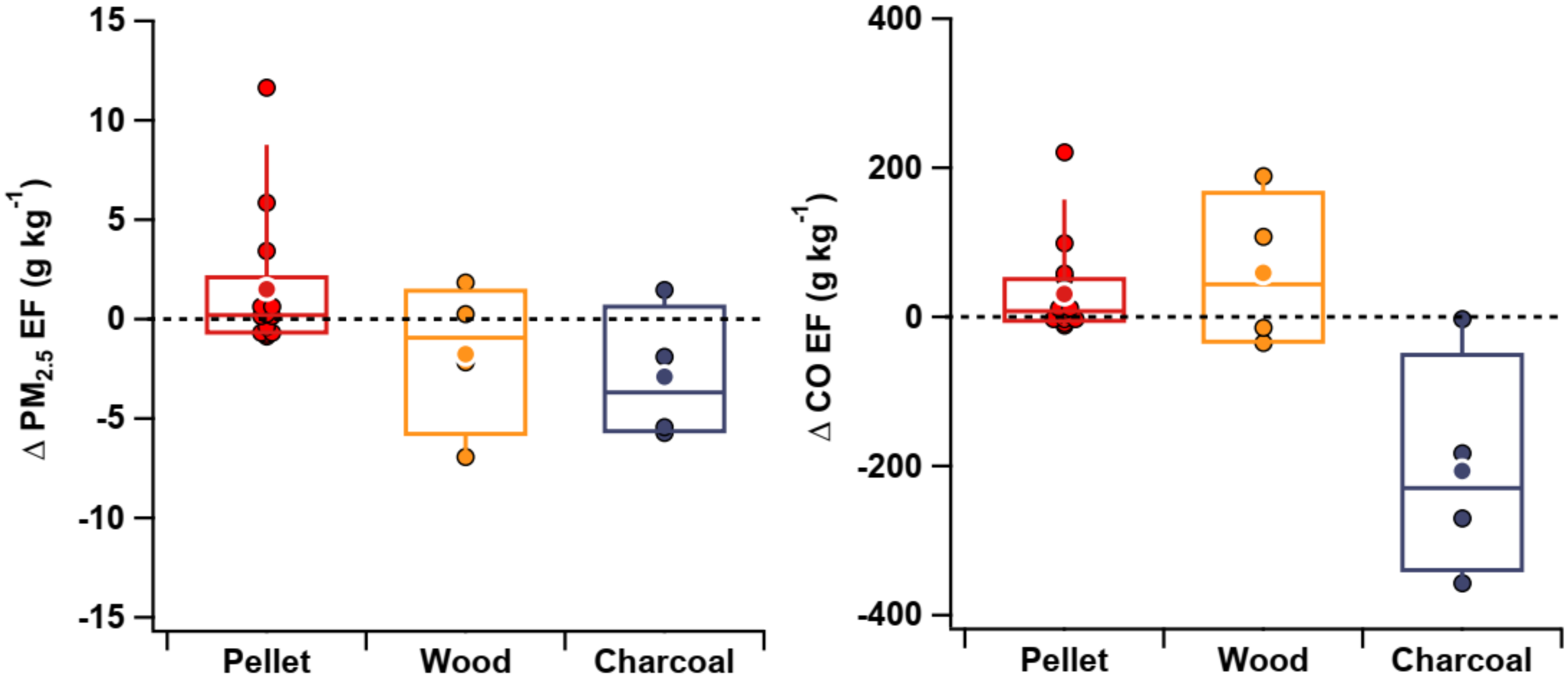
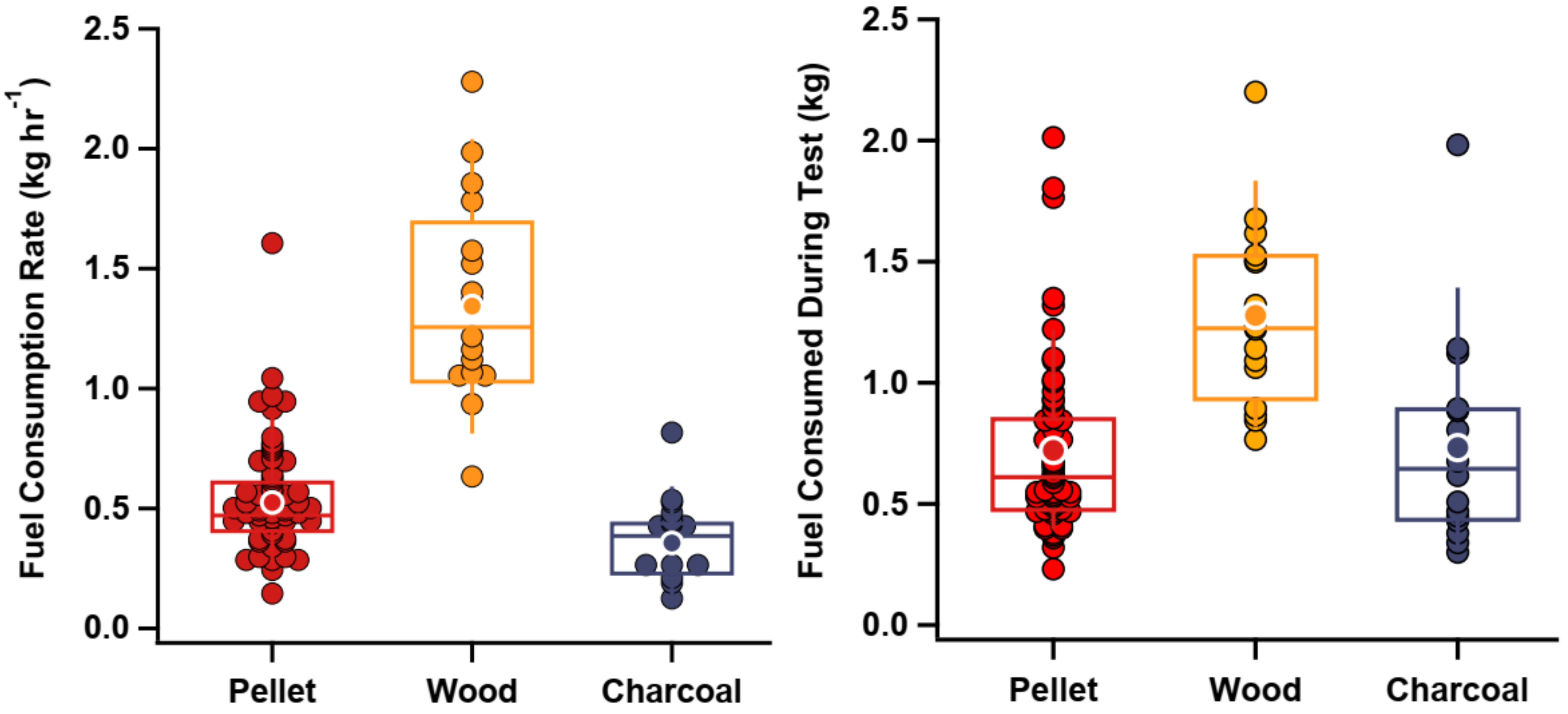
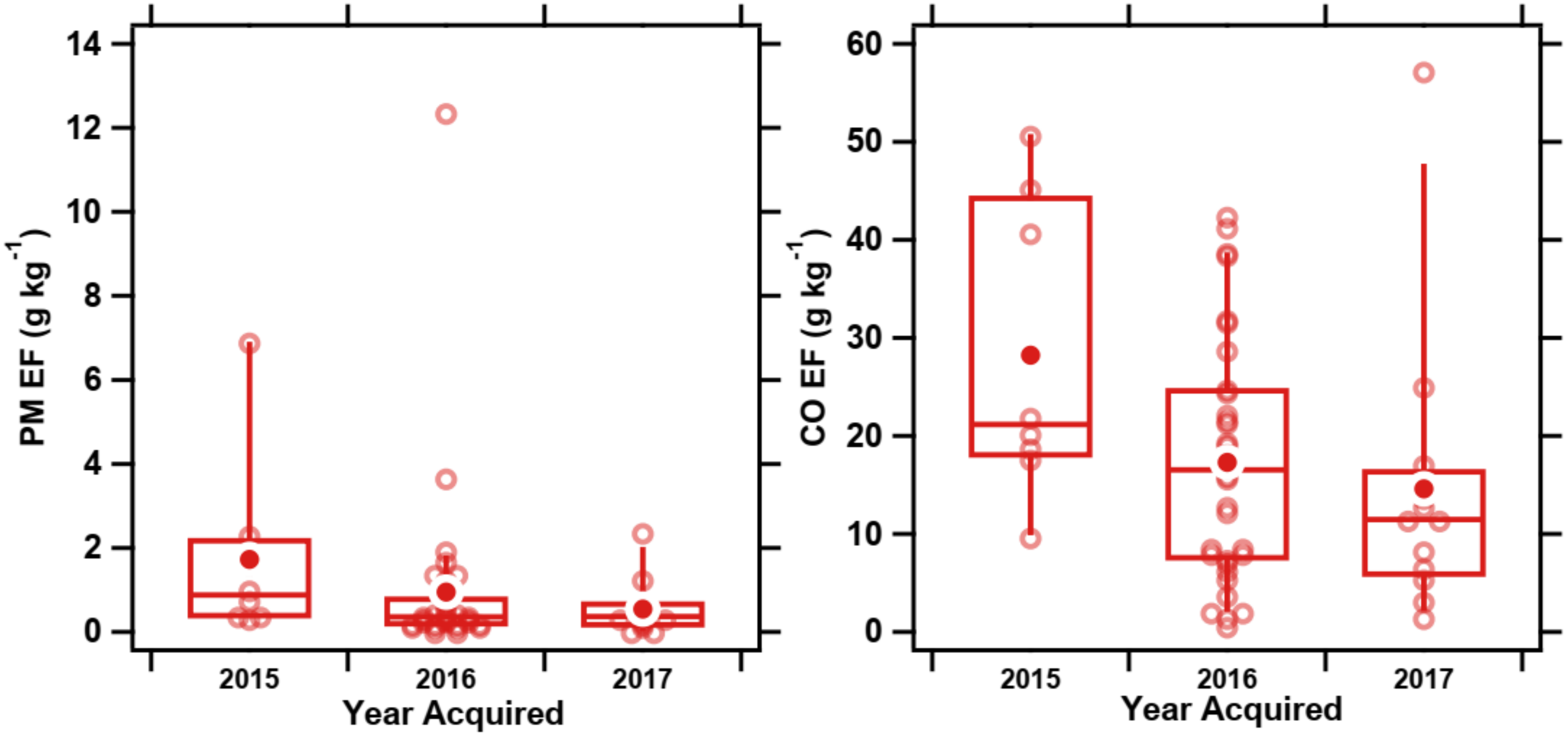
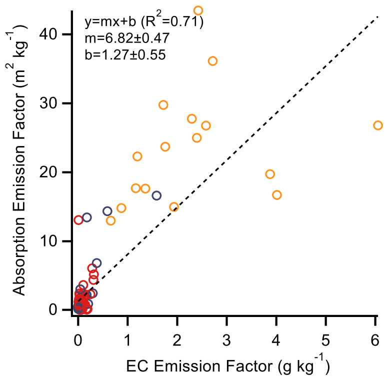
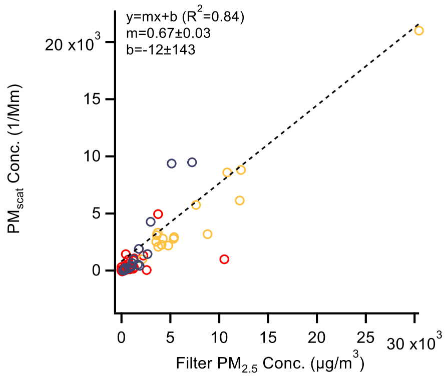

15
10
5
0
-5
-10
-15
Δ $PM_{2.5}$ EF (g kg^{-1})
Pellet
Wood
Charcoal
400
200
0
-200
-400
Δ CO EF (g kg^{-1})
Pellet
Wood
Charcoal

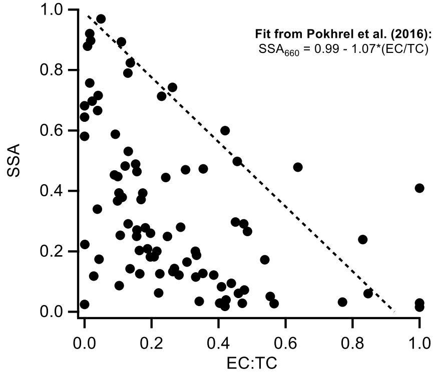

Fuel Consumption Rate (kg hr^{-1})
2.5
2.0
1.5
1.0
0.5
0.0
Pellet
Wood
Charcoal
Fuel Consumed During Test (kg)
2.5
2.0
1.5
1.0
0.5
0.0
Pellet
Wood
Charcoal



PM EF (g kg-1)
14
12
10
8
6
4
2
0
2015
2016
2017
Year Acquired
CO EF (g kg-1)
60
50
40
30
20
10
0
2015
2016
2017
Year Acquired


y=mx+b (R2=0.71)
m=6.82±0.47
b=1.27±0.55
Absorption Emission Factor (m2 kg-1)
EC Emission Factor (g kg-1)
0
10
20
30
40
0
1
2
3
4
5
6


y=mx+b (R2=0.84)
m=0.67±0.03
b=-12±143
PMscat Conc. (1/Mm)
Filter PM2.5 Conc. (μg/m3)
20 x103
15
10
5
0
0
5
10
15
20
25
30 x103


Fit from Pokhrel et al. (2016):
SSA660 = 0.99 - 1.07*(EC/TC)
SSA
EC:TC
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0