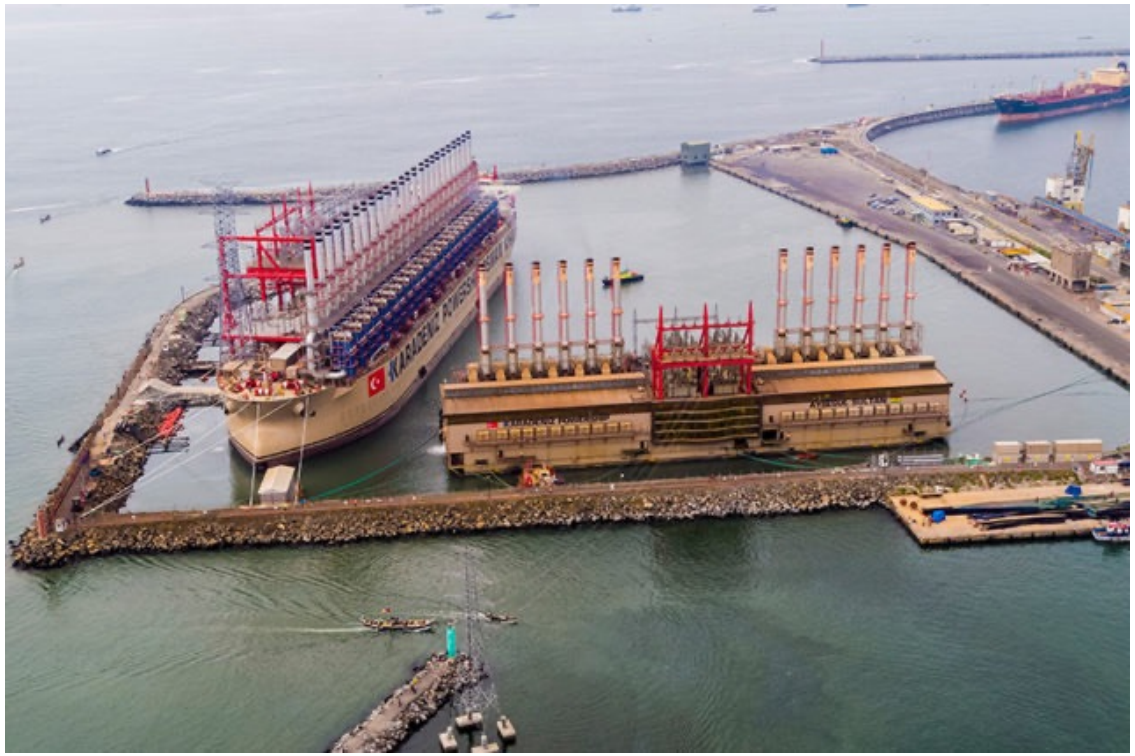
Greenhouse gas and air pollutant emissions from power barges (powerships)

Eloise A Marais, UCL, https://maraisresearchgroup.co.uk/



with **Orianna Akker** (University of Bath) and **Christine Wiedinmyer** (CIRES)

RSC Desktop Seminar **1 June 2022**

An emerging source: Power barges (powerships)

Generating capacity increased 13-fold in a decade

A popular quick to install gas-to-electricity solution in regions with electricity shortages

Need to know air pollutant precursor and climate-altering greenhouse gas emissions

Used in South and Central America, Africa, SE Asia, the Middle East

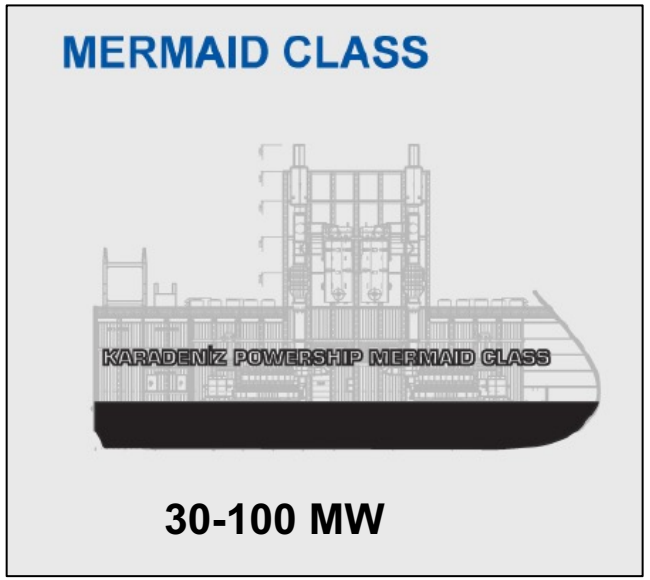
From 144 MW in 2010 to 2.6 GW in 2020. 4.4 GW under construction.

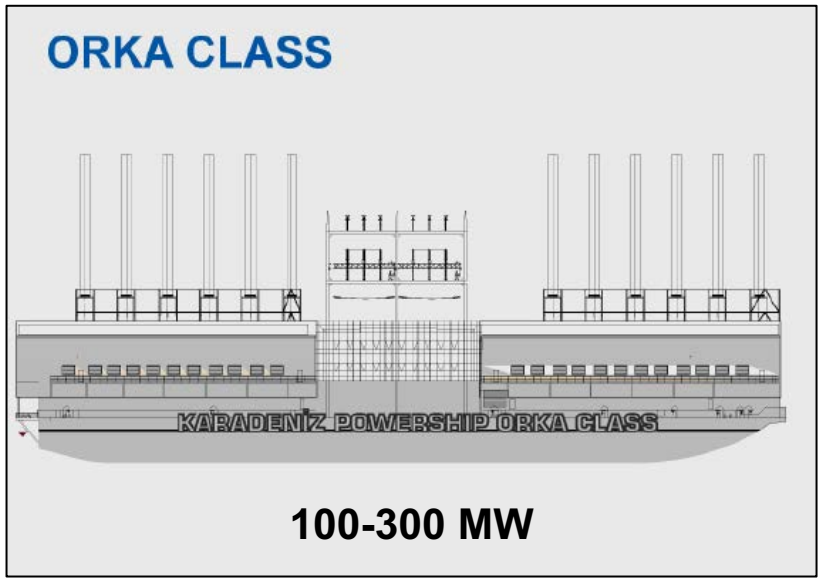
Not limited to coastal countries (Zambia power share with Mozambique)

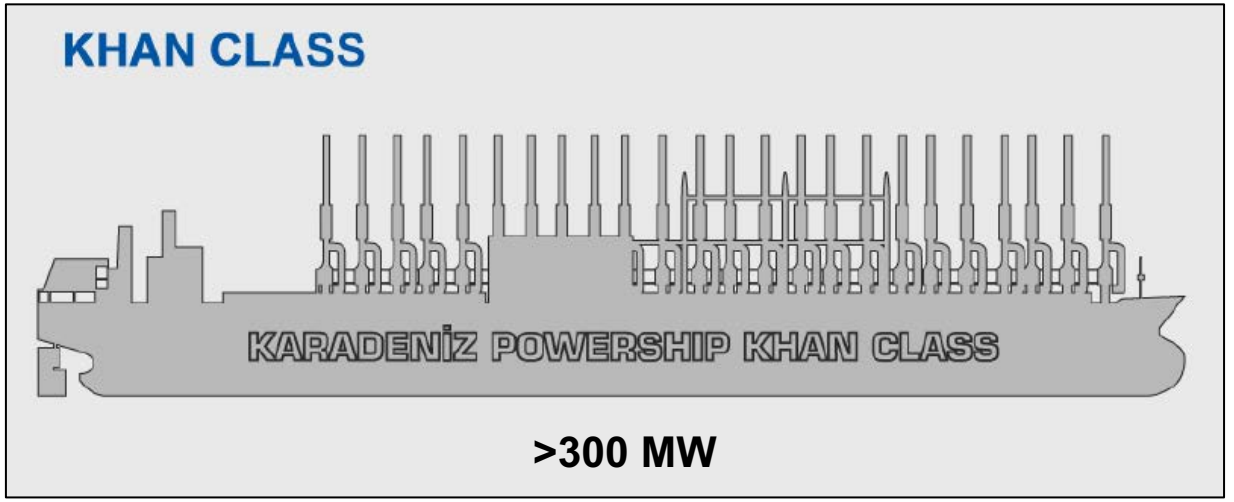
Fuel

Most use natural gas (**NG**)

Classes of Powerships



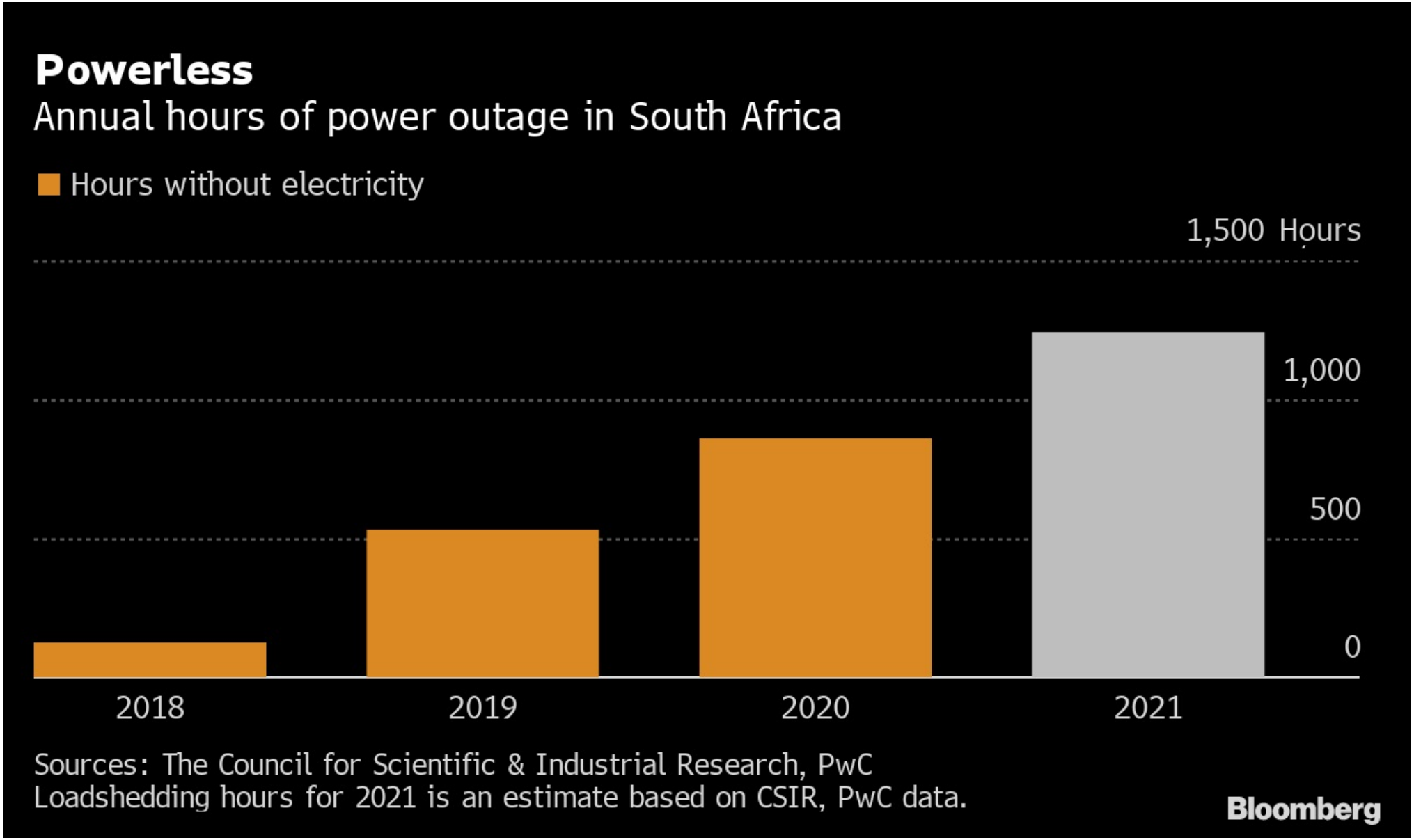




Range from <50 MW to 470 MW

[https://ecowapp.org/sites/default/files/wapp_karpowership_introduction.pdf]

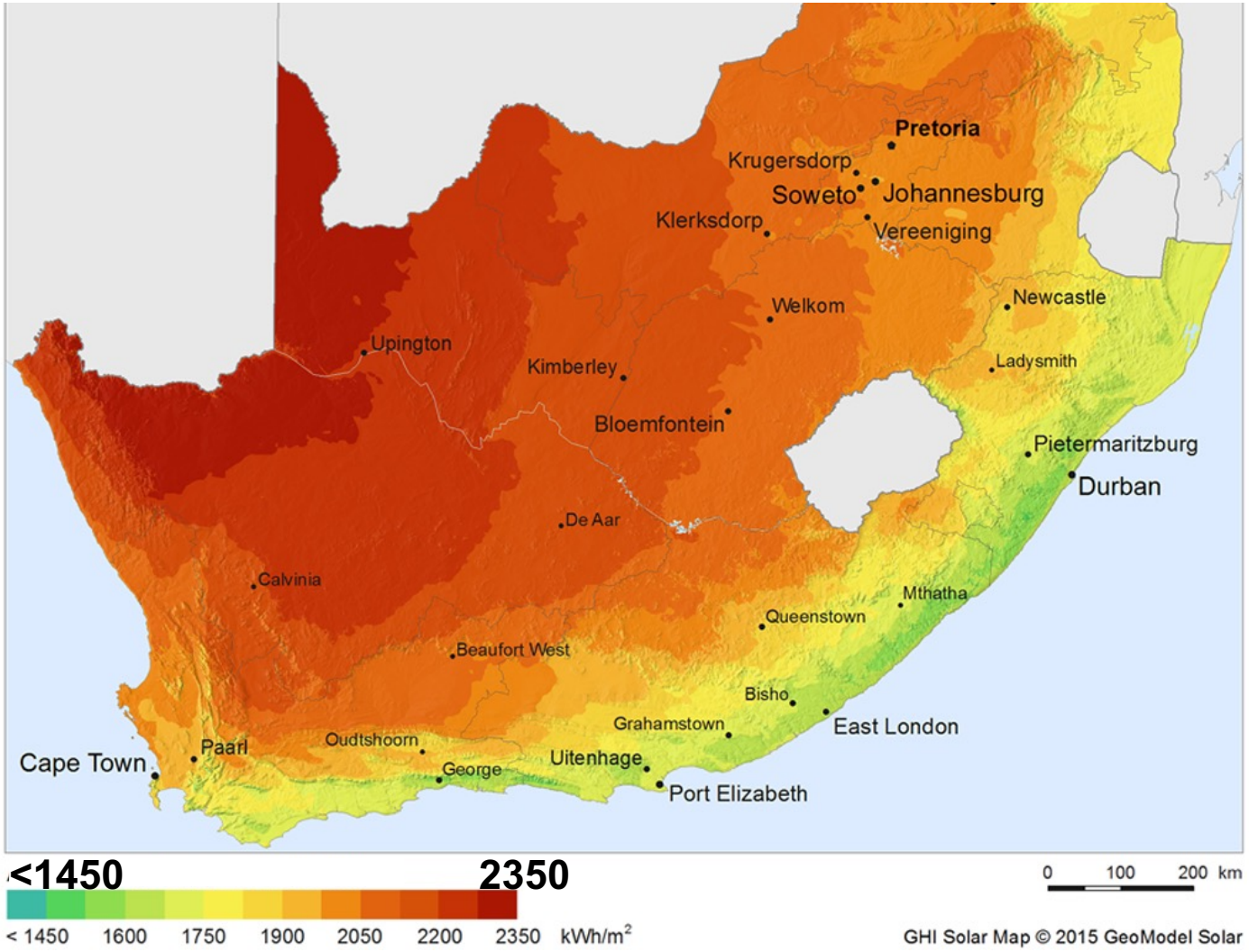
Proposed Deployment to Ports in South Africa



[https://www.bloomberg.com/news/articles/2021-11-24/stuck-with-ailing-eskom-south-africa-confronts-more-blackouts]

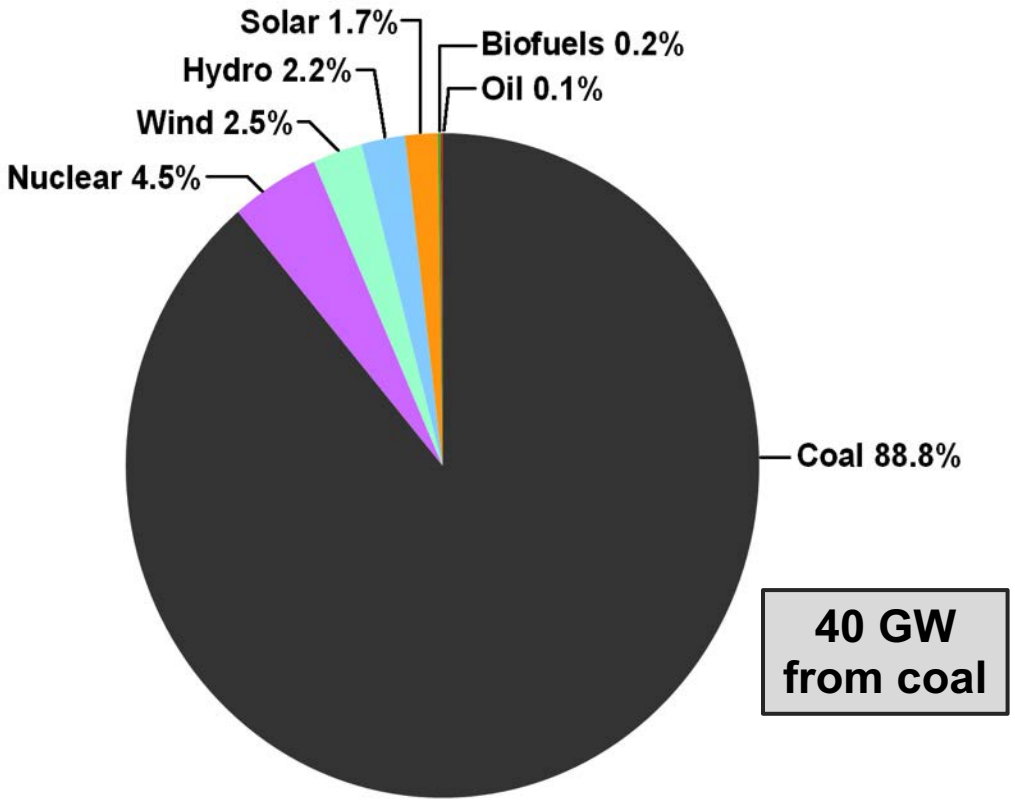
Proposed Deployment to Ports in South Africa

Solar energy resource in kWh m^{-2} (1994-2013 mean)



Source: https://www.csir.co.za/study-shows-abundance-wind-and-solar-resources-south-africa

Electricity production by energy type (2018)



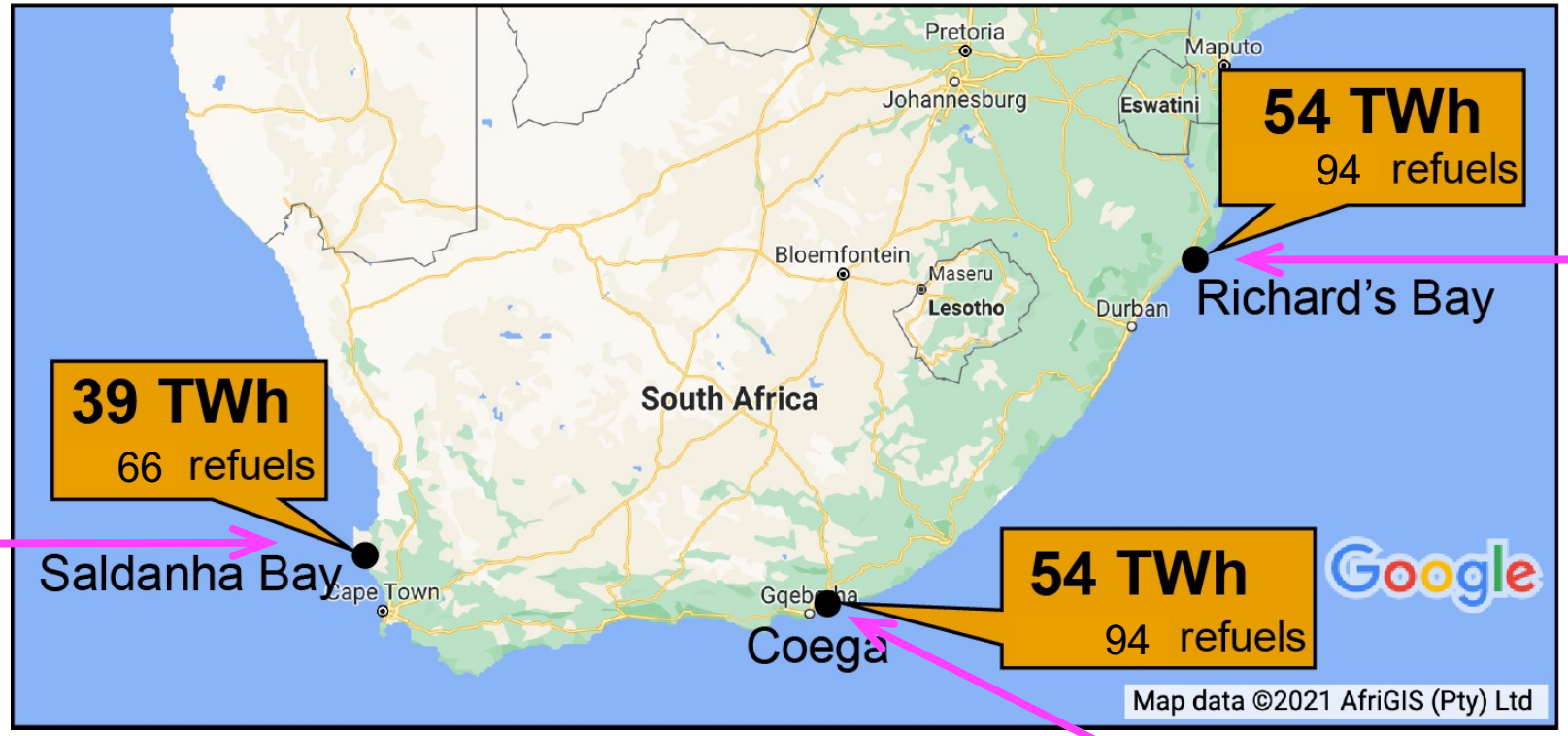
40 GW from coal

Electricity generating capacity overwhelmingly dominated by coal

Source: EIA data on Wikipedia

Locations of Proposed South African Powerships

Required to operate for 20 years 16.5 hours a day (68.75% capacity factor)



450 MW

320 MW

450 MW

MW: megawatts

TWh: terawatt hours

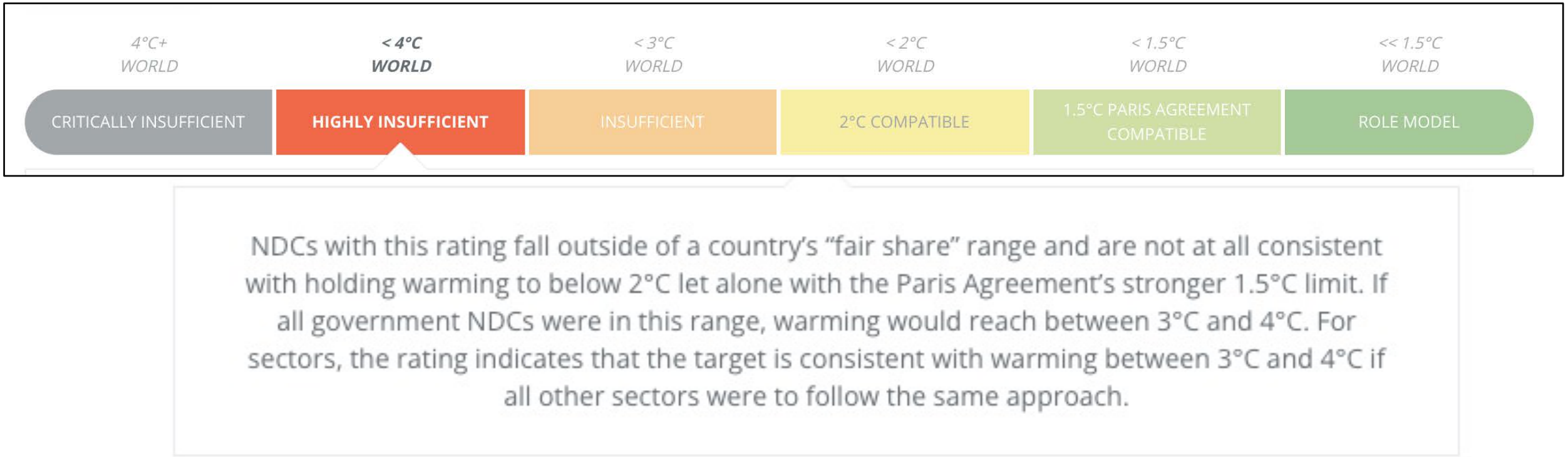
LNG required over 20 years: 51 million m^3

Total **electric energy** over 20 years: 147 TWh

Total **refuels**: 254 (roughly monthly)

South Africa's GHG Emissions and Paris Climate Accord Commitments

Climate change is the greatest challenge facing humanity (most vulnerable will be most affected)



https://climateactiontracker.org/countries/south-africa/

South Africa 14th largest GHG emitter and commitments rated **highly insufficient**

Natural gas only effective transitionary fuel if methane (CH_4) leakages are kept to a minimum

South Africa is the Climate Change Poster Child

Supply Chain Steps Contributing to GHG and Air Pollutant Emissions

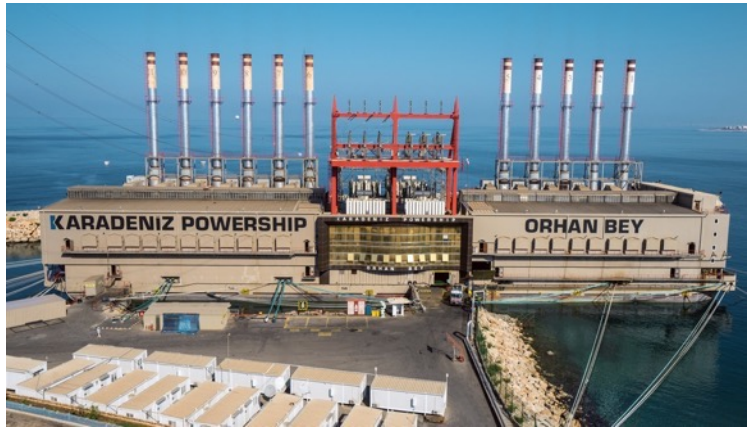
Upstream gas production

Liquefaction

LNG to be provided by Shell

Tanker transport

Storage and regasification



Electricity production

Largest emissions: upstream for CH_4; electricity production for CO_2; tanker return trip for air pollutants

Emissions Calculation

Standard approach: product of activity factors (**AF**) and emission factors (**EF**)

$$E_i = \sum_{j=1}^{n} AF_j \times EF_i$$

Activity Factors (AFs):

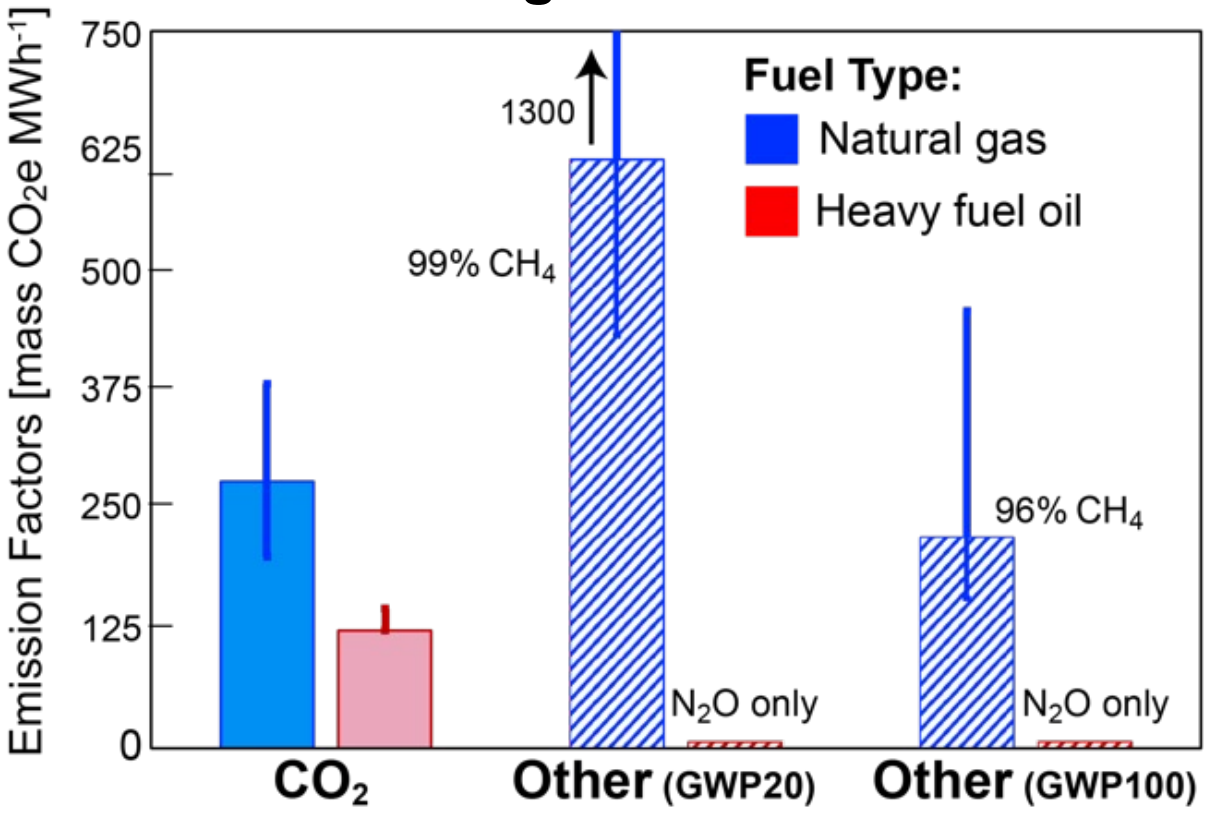
electric energy generated (**powerships**), energy needed (**liquefaction**, **regasification**, **storage**), natural gas consumed (**tanker trips, methane leakage** rates)

Emission Factors (EFs):

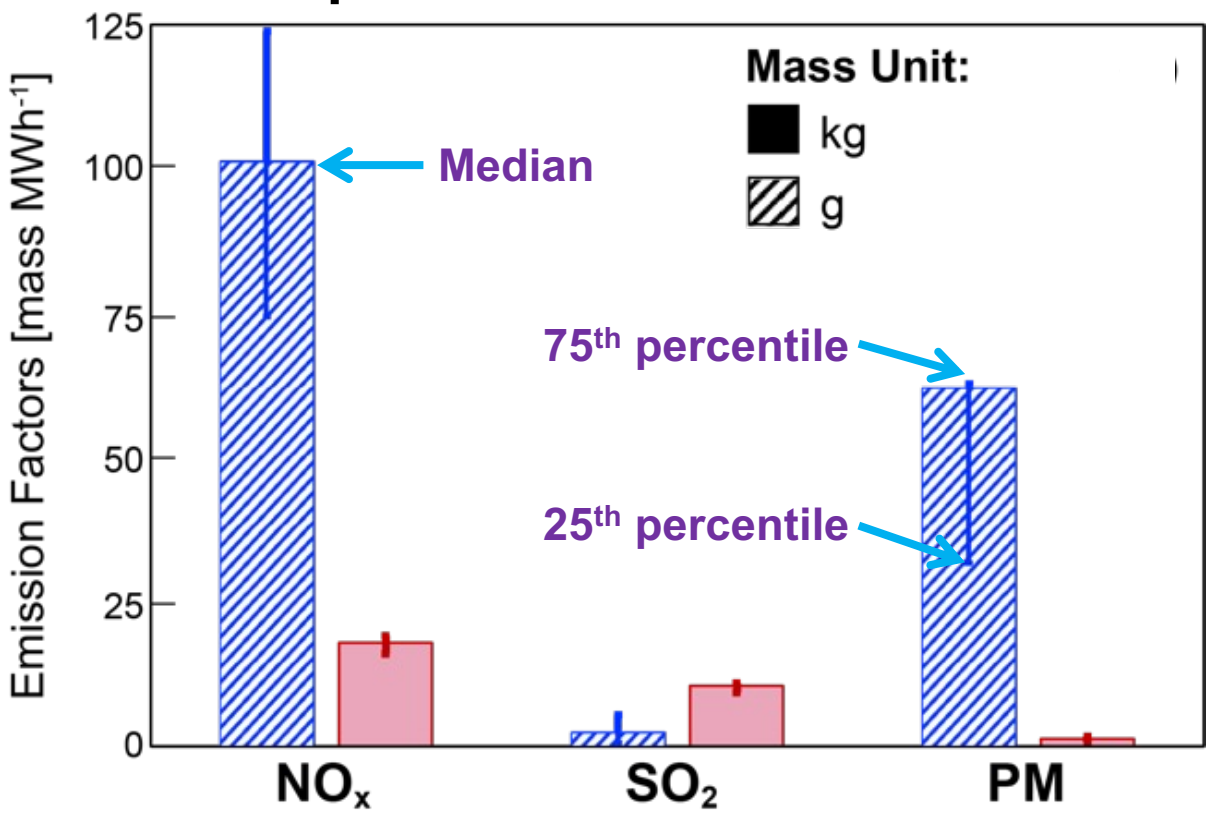
compiled from reliable reports and handbooks (EPA, EMEP) and peer-reviewed literature

Emission Factors for Natural Gas and Ship Oil

Greenhouse gas emission factors



Air pollutant emission factors



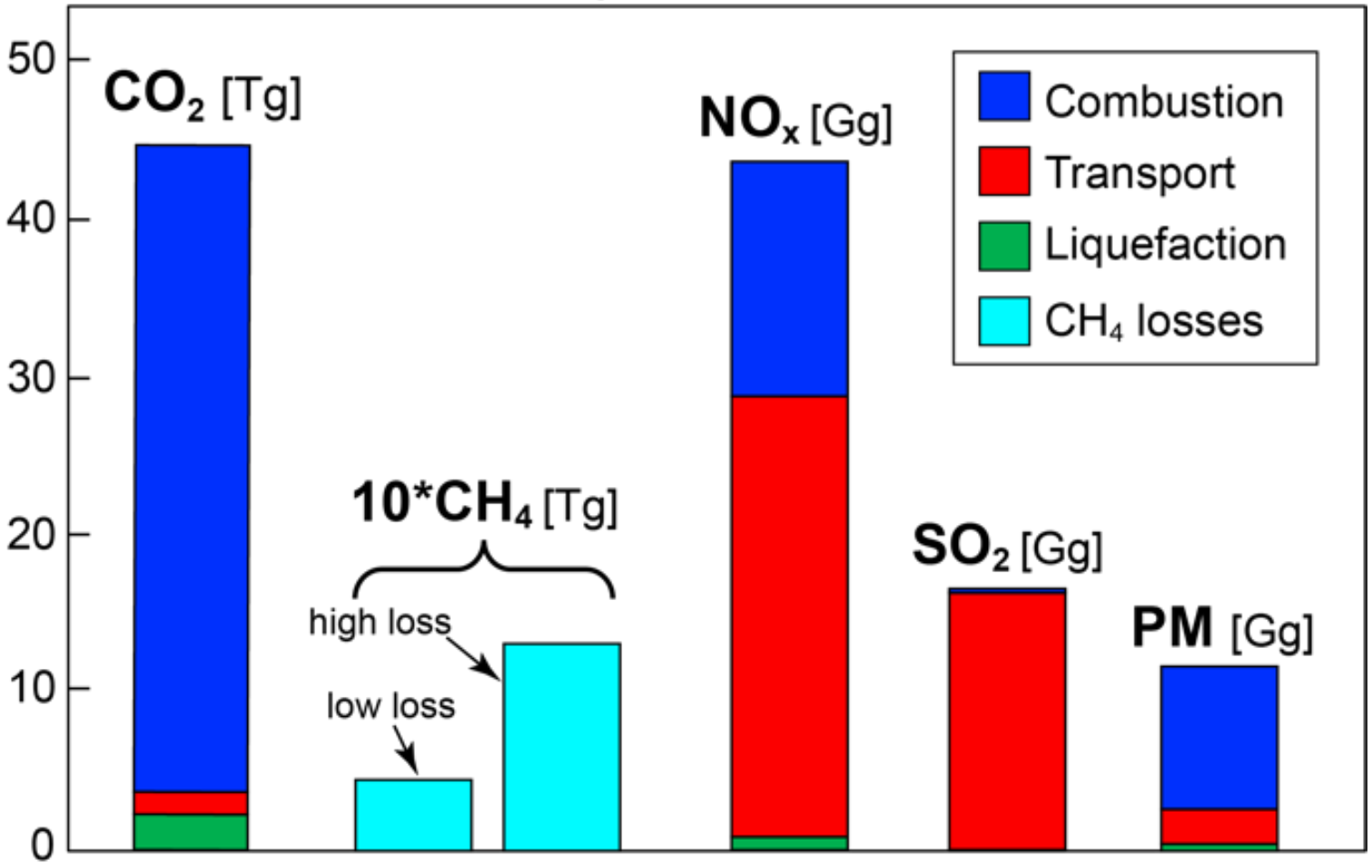
GWP: Global Warming Potential (CH_4 25-times greater than CO_2)

Emission factors for powerships from traditional gas-fueled power plants and reciprocating engines

Wide range of values reported, especially for NO_x (75-125 g MWh^{-1}).

Greenhouse gas and air pollutant emissions for SA Powerships

Total emissions for 20-year adoption of powerships



1 Tg = 1 million tonnes

1 Gg = 1 thousand tonnes

PM: particulate matter

Transport emissions depend on LNG location (Nigeria assumed) and controls on ship emissions.

CH_4 emissions range from 0.5 Tg at 2.1% loss rate to 1.3 Tg at 6.1%.

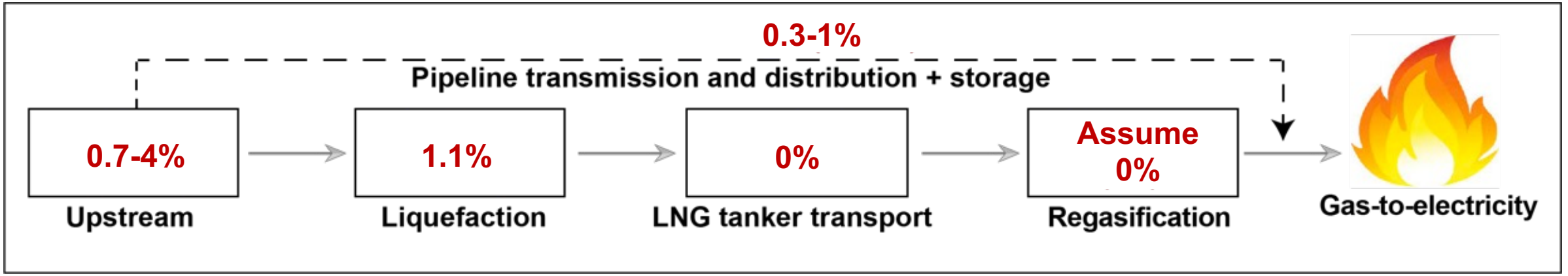
Combustion largest source of CO_2 (92%) and PM (78%), **transport** (ship oil combustion) largest source of NO_x (64%) and SO_2 (98%)

Annual Greenhouse Gas Emissions

Includes CO_2 and CH_4 and smaller contributions from nitrous oxide (N_2O) and sulfur hexafluoride (SF_6)

Converted to same scale (CO_2-equivalents)

Methane loss rates in each supply chain step



No information on the regasification step

Greatest losses during upstream activities

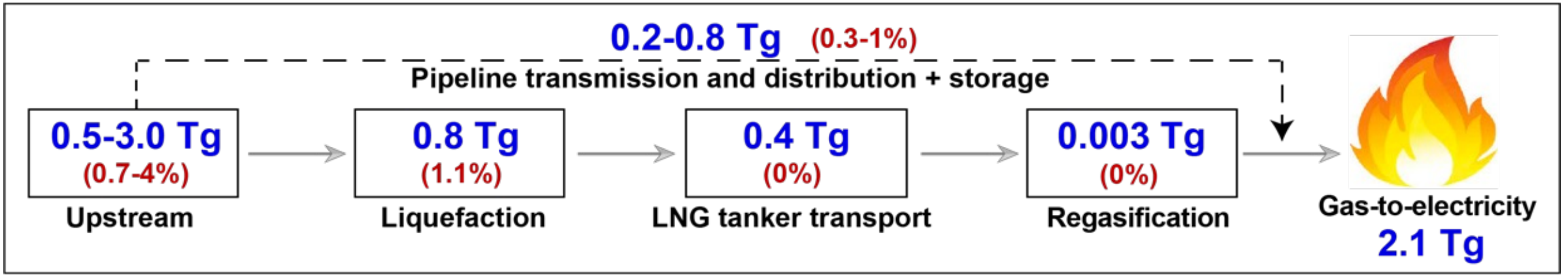
Totals **2.1-6.1%** (similar to values used in lifecycle analysis models)

Annual Greenhouse Gas Emissions

Includes CO_2 and CH_4 and smaller contributions from nitrous oxide (N_2O) and sulfur hexafluoride (SF_6)

Get CH_4 on CO_2e scale: multiply by 25 on 100-year time horizon and 72 on 20-year time horizon

Greenhouse gas emissions on 20-year time horizon



Totals **4.0-7.1 Tg CO_2e** (**2.6-3.8 Tg CO_2e** on 100-year time horizon). 1-2% of SA's total GHG emissions

Gas-to-electricity is 92% of total in absence of CH_4 losses and 30% of total for 6.1% loss rate

Normalized to electricity production: **540-970 kg CO_2e MWh^{-1}** (similar to 950-1000 kg CO_2 MWh^{-1} for South Africa's coal-fired power plants)

Comparison of air pollutant emissions to national standards

National Minimum Emissions Standards reported as mass (milligrams) pollutant per volume unit (cubic metres) gas burned

Pollutant	Powership Emissions [mg m^{-3}]		National Emission Standards [mg m^{-3}]	
	Median	25th-75th percentile	NG combustion installations	Reciprocating engines
PM	285	146-288	10	50
NO_x as NO_2	465	342-569	50	400
SO_2	11	8.0-14	400	1170

NG combustion installations burn NG only, reciprocating engines burn gas and liquid fuels.

PM and NO_x have potential to be out of compliance with emissions standards, but this will depend on operating conditions (combustion efficiency) and which standards policymakers use

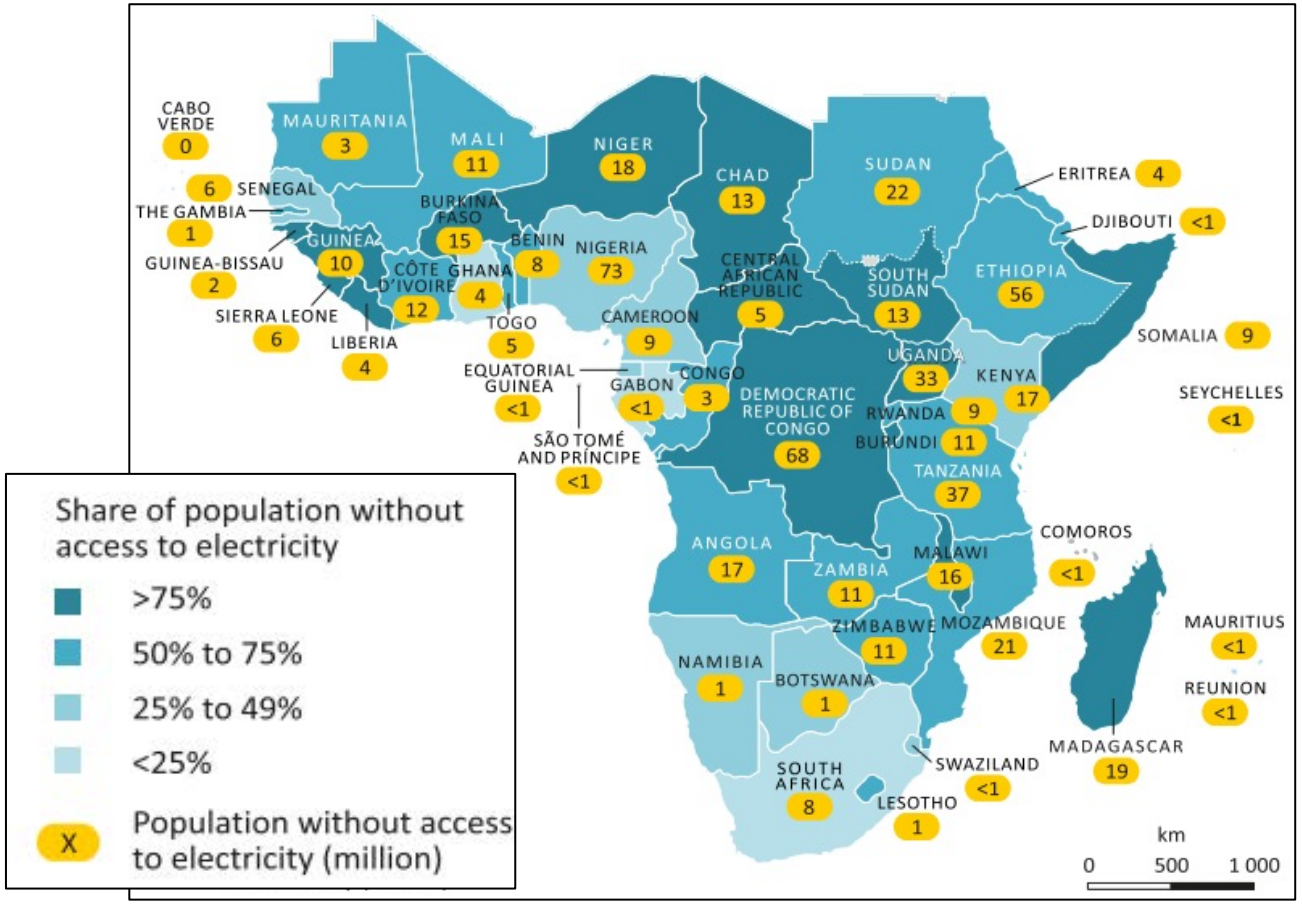
Annual Emissions from Global Fleet of Powerships

2.6 GW currently operating: 4.4 Tg CO_2, 0.8-3.2 Tg CH_4, 1.6 Gg NO_x and 1.0 Gg PM

3-fold increase when additional 4.4 GW deployed

Wider Adoption across Sub-Saharan Africa (SSA)

Percent of population without access to electricity



Totals ~600 million people

[https://tinyurl.com/3phhafpt]

If every other SSA country adopts 1.2 GW generating capacity:

Address 11% of generating capacity deficit, assuming energy needs similar to South Africa (~0.8 GW per person).

Annual GHG emissions of **110-160 Tg CO_2e** or **5-7%** of total reported gross GHG emissions for SSA in 2018

Summary and Concluding Remarks

- 20 year commitment by South Africa could add 80 to 140 million tonnes CO_2e greenhouse gases to the atmosphere.
- Air pollutants from powerships could be out of compliance with South African emissions limits.
- Current contribution of powerships GHG emissions to global total is small, but wider adoption to alleviate global electricity access deficits could make substantial contribution.
- Climate and air quality impact on atmosphere depends largely on preventing CH_4 losses at all steps and on enforcement of emissions limits.
- Other worrying environmental issues: noise pollution, bird and marine life, fish populations that local communities rely on.
- More information needed about specific operating conditions throughout supply chain and emission factors of GHGs and pollutants characteristic of powerships.

Link to Paper (free to access): https://pubs.rsc.org/en/content/articlepdf/2022/va/d1va00049g

Any Questions?