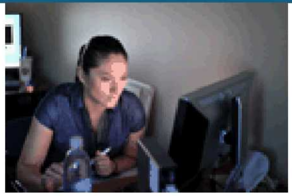
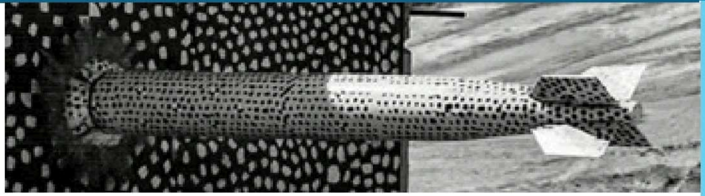
This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

SAND2020-2323C

Inverter Faults & Failures: Common modes & patterns





Thushara Gunda

Photovoltaics Reliability Workshop

February 27, 2020

SANDXXX

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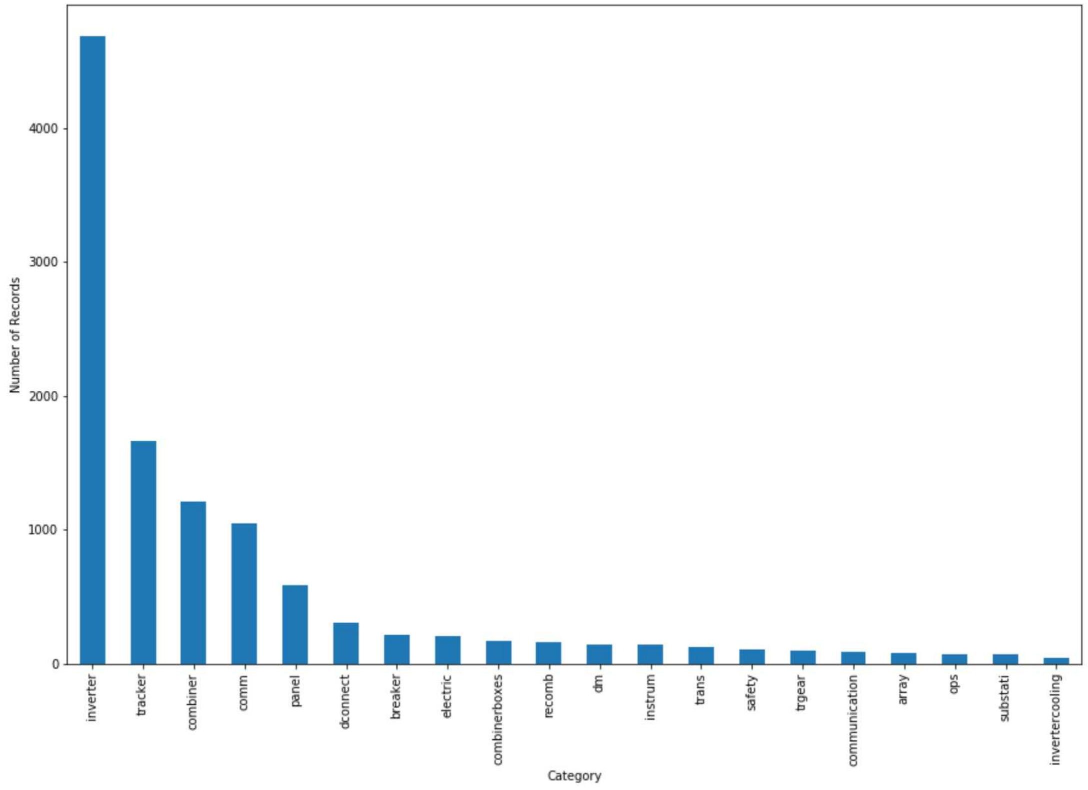
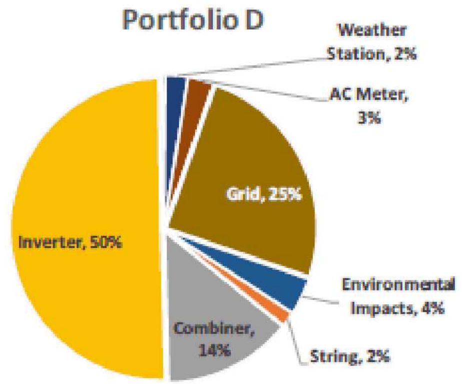
Inverters dominate failures



EPRI (2019)



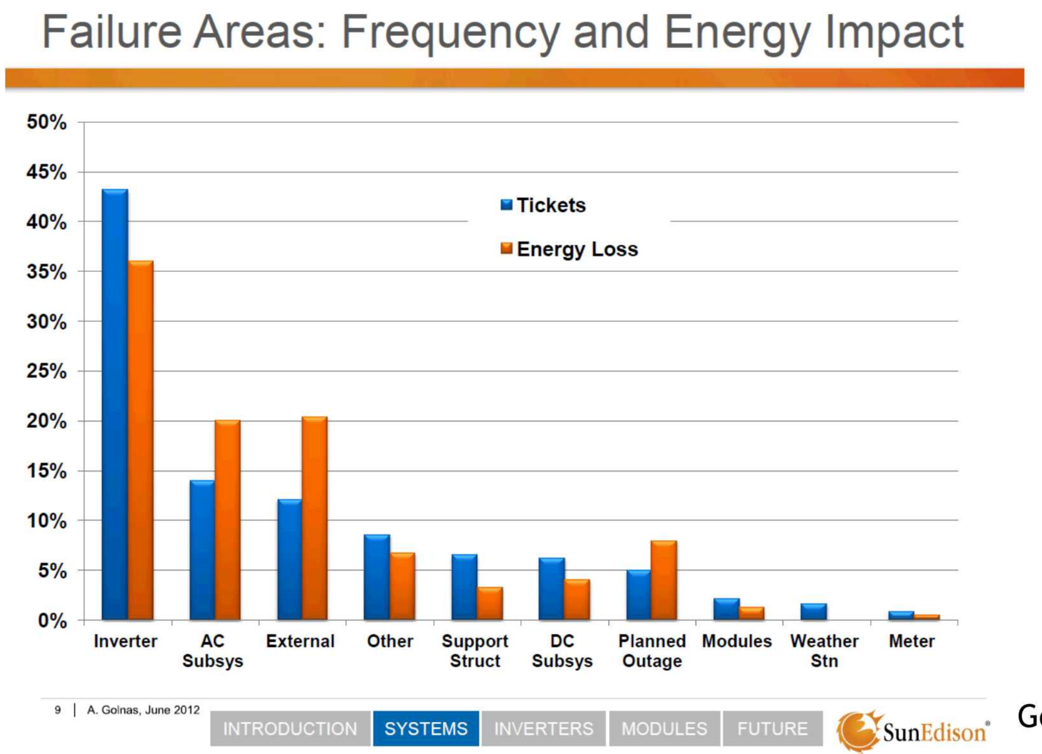
Component event percentages for Portfolio D

Freeman et al (2018)

Table 1
Failures frequency [9].

#	Failure subsystem	Frequency, %
1	Inverter	43
2	AC subsystem	14
3	External	12
4	Support structure	6
5	DC subsystem	6
6	Modules	2

Cristaldi et al (2015)



Golnas (2012)

Cost Implications

PV O&M BUDGET COMPONENTS AND COSTS

Based on PV system O&M estimates published by the Electric Power Research Institute, a utility-scale project O&M budget, excluding system monitoring plan, may cost between $10 to $45/kW per year.

Even though this list of budget items is not exhaustive, it demonstrates how O&M costs may vary widely. For example, "panel washing" is listed as "per event" occurrence, meaning that budget item can easily double or triple per year to ensure output performance if the PV plant is located in a rural, arid environment. One of the most varying cost is "spares". Asset owners expecting high reliability from system performance will require more stringent spare parts management, such as keeping the most critical equipment like inverters and transformers available at all times.

TABLE 1. ESTIMATED PV O&M BUDGET COMPONENTS AND COSTS.

BUDGET ITEM	BUDGET RANGE ($/KW-YR)	NOTES
Overall Budget	$10.00-45.00/ kW-yr*	Variable based on whether cost plus, extended warranty, and other items are included. Also, some O&M activities are non-linear which can affect overall outlays.
General Site Maintenance	$0.20-$3.00/ kW-yr	Variable based on system size, location. (e.g., desert environments are less expensive than snowy locales that require snow removal from critical areas), and frequency of activity.
Wiring/Electrical Inspection	$1.40-$5.00/ kW-yr†	Includes inspection of wires, junctions boxes, combiner boxes, AC/DC disconnects, service panel, etc.; string testing. Prices will differ, among other things, based on whether inspection covers 10% or 100% of the plant.
Panel Washing	$0.80-$1.30/ kW-yr†	Variable based on technology (different form factors), cleaning regimen, prevailing wages, and other factors. As a result, some stakeholders provide cost metrics on a $/module basis.
Vegetation Management	$0.50-1.80/kW-yr†	Variable based on site characteristics and acreage. Often a "cost-plus" contingency item.
Inverter Maintenance	$3.00-7.50/kW-yr†	Activity typically encompasses cleaning of filters, torqueing, thermal imaging of internal components, minor equipment repair, etc.
Inverter Replacement	$6.00-10.00/kW**	Typically, plant owners only budget for one inverter replacement activity after the initial warranty period. Price ranges encompass different utility-scale inverter sizes and models.
Racking / Tracker Maintenance	Insufficient data	Racking maintenance is negligible, however tracker maintenance is more costly. Specific data points for the latter activity are insufficiently available.
Spares	$2.00-$20.00/ kW-yr***	Most critical spares to have on hand include fuses, contacts, wiring, inverter parts (circuit boards, filters, fans, etc.), disconnect switches, and modules.

Source: EPRI, 2015 December, "Budgeting for Solar PV Plant Operations & Maintenance: Practices and Pricing"

Notes: Budget numbers exclusively for utility-scale plants; they encompass an entire range of baseline, cost-plus, and warranty terms.
* Constituent components of the O&M budget are non-linear and will not necessarily add up to the overall budget on a $/kW-yr basis.
** Inverter replacement metrics are based on a $/kW, and cover a one-time equipment replacement and installation activity over the course of a plant's lifetime.
*** Budget range for spares primarily encompasses equipment procurement and storage costs.
† Price points based on a 1x annual frequency (i.e., per event)

SEPA (2019)

Study Objective

- Analysis of maintenance logs to identify most common failures modes within inverters

- Identification of variabilities across climate, equipment, and other factors

Dataset

6 industry partners

650+ sites (2008-2019 COD)

80% utility-scale

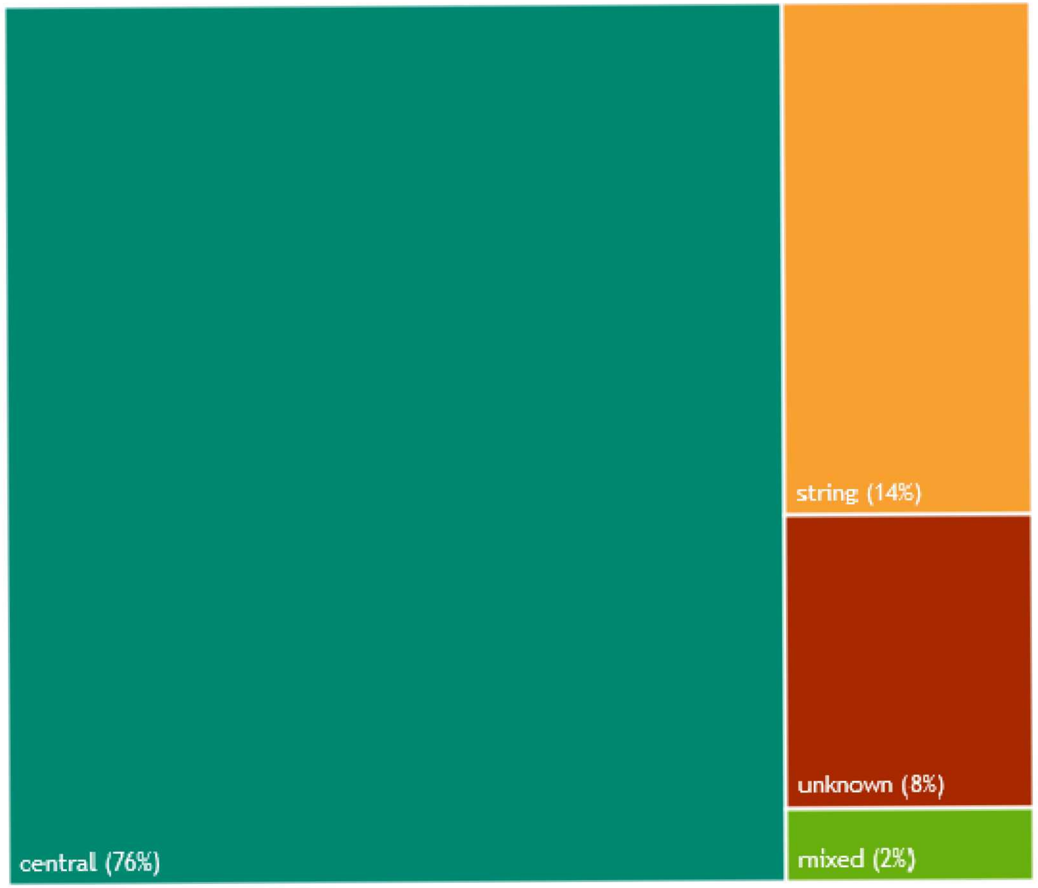
5.2 GW in DC Capacity (4.0 AC_{GW})

26 U.S. states

13 climate zones

Central inverter-type dominated

20K records (97% CM)

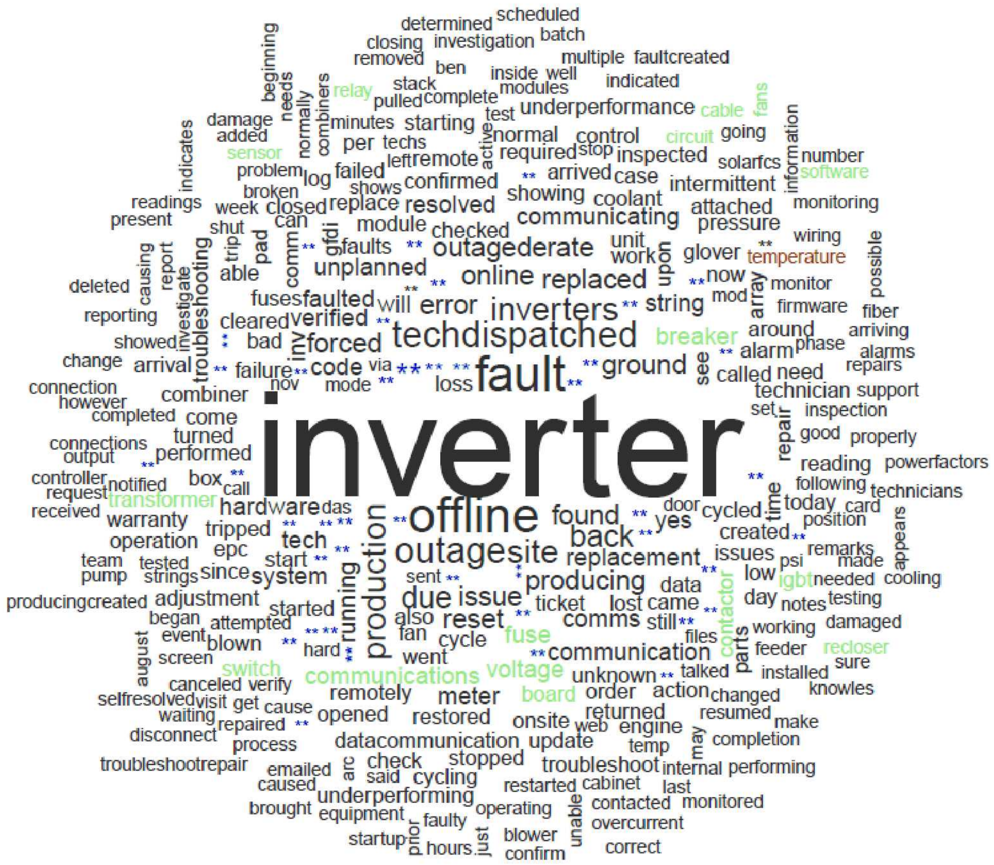


What do the tickets contain?

Varying level of detail

Common elements include site location, time, and description

Used text analytics + machine learning to develop a consistent “asset” label across the logs



Common terms in tickets
Component/subsystems
Weather terms

Failure Modes

Failure Modes: Literature Review

Common modes include:

- Subsystems: storage capacitors, power stage drivers, cooling, isolation transformers
- Functional aspects: controller, interlock, internal, matrix, design
- Stages: manufacturing and inadequate design, control, and electrical components
- Root cause: parts/materials, external, software, other, unknown, construction, preventative maintenance

Common components include: fan motor, air filters, control software, power supply, AC contactor, DC contactor, capacitors, fuses, GFI components, IGBT matrix/driver control board, inductors, …

➢ In this work, failure modes focus on replacement (i.e., components that can be replaced/have individual part #s)

Inverter Subsystems

IGBTs

PCBs/Cards (control, communications, accessory, sensor, driver)

Capacitors

Contactors

Heat Mgmt. systems (fans, motors, pumps, liquid, filters)

Sensors

Fuses

Switches

Power supply

Reactor/inductor

Breakers

AC Output

Enclosures

Transducers

External to Inverter

- Cabling
- Recloser
- Transformer
- Relay

Systems-level

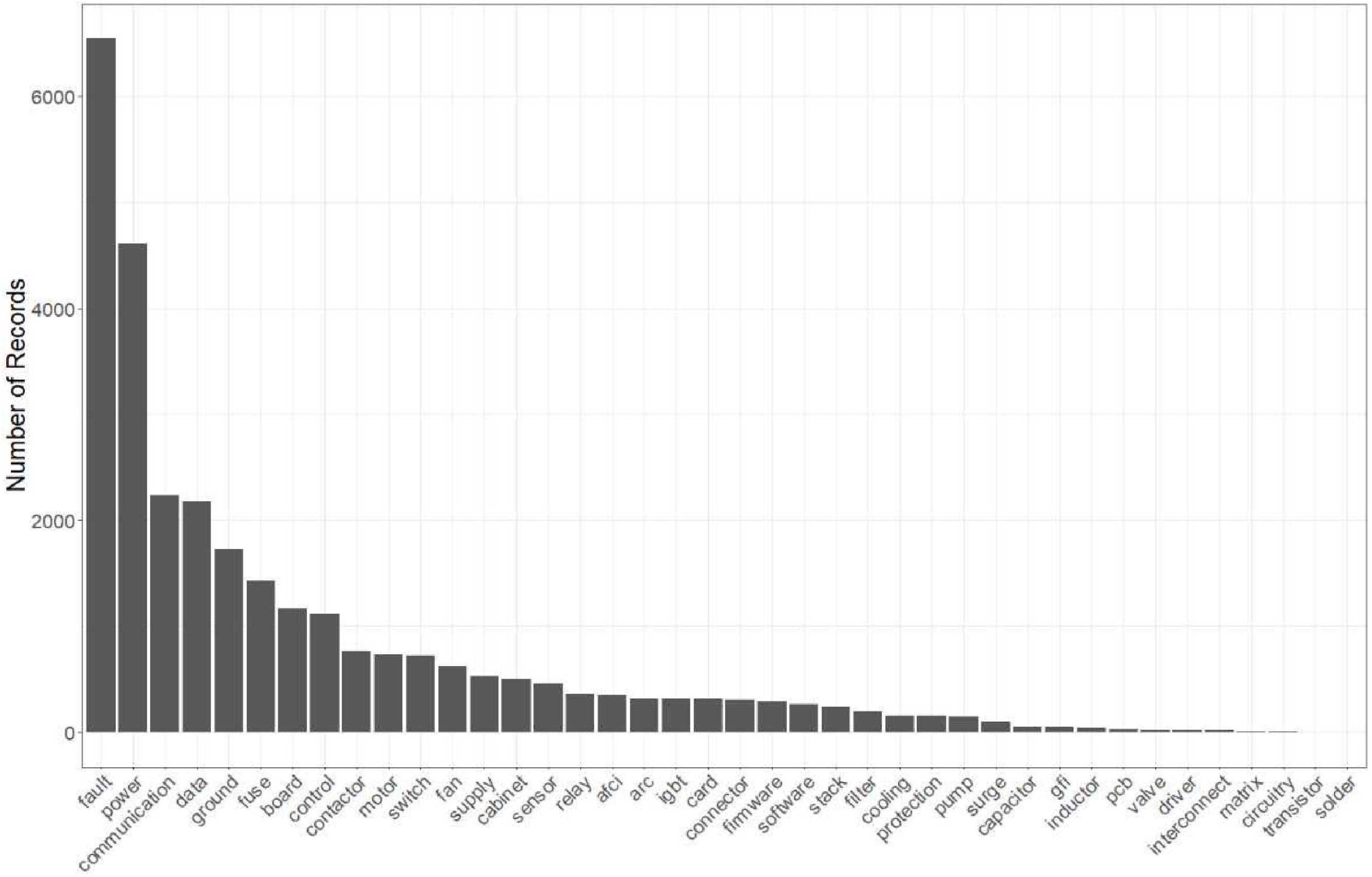
- Configuration (hardware)
- Software (settings, updates)
- Communications

Data Patterns

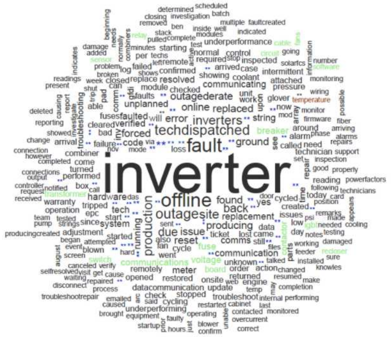
Key Terms in Data

Single term searches provide some insight

Combinations of words would be more informative



Topic Modeling



Collection of O&M tickets

Latent Dirichlet Allocation

hardware
replacement
offline
…

ground
fault
wiring
…

power
cycle
supply
…

Topics: Clusters of words

Inverter cycling due to hardware malfunction. Power cycle.

hardware

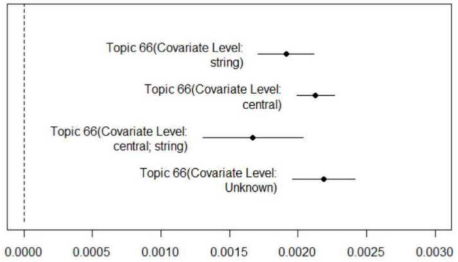
power cycle

Inverter #4 down. AC fuse replaced. 24 volt power supply replaced.

fuse

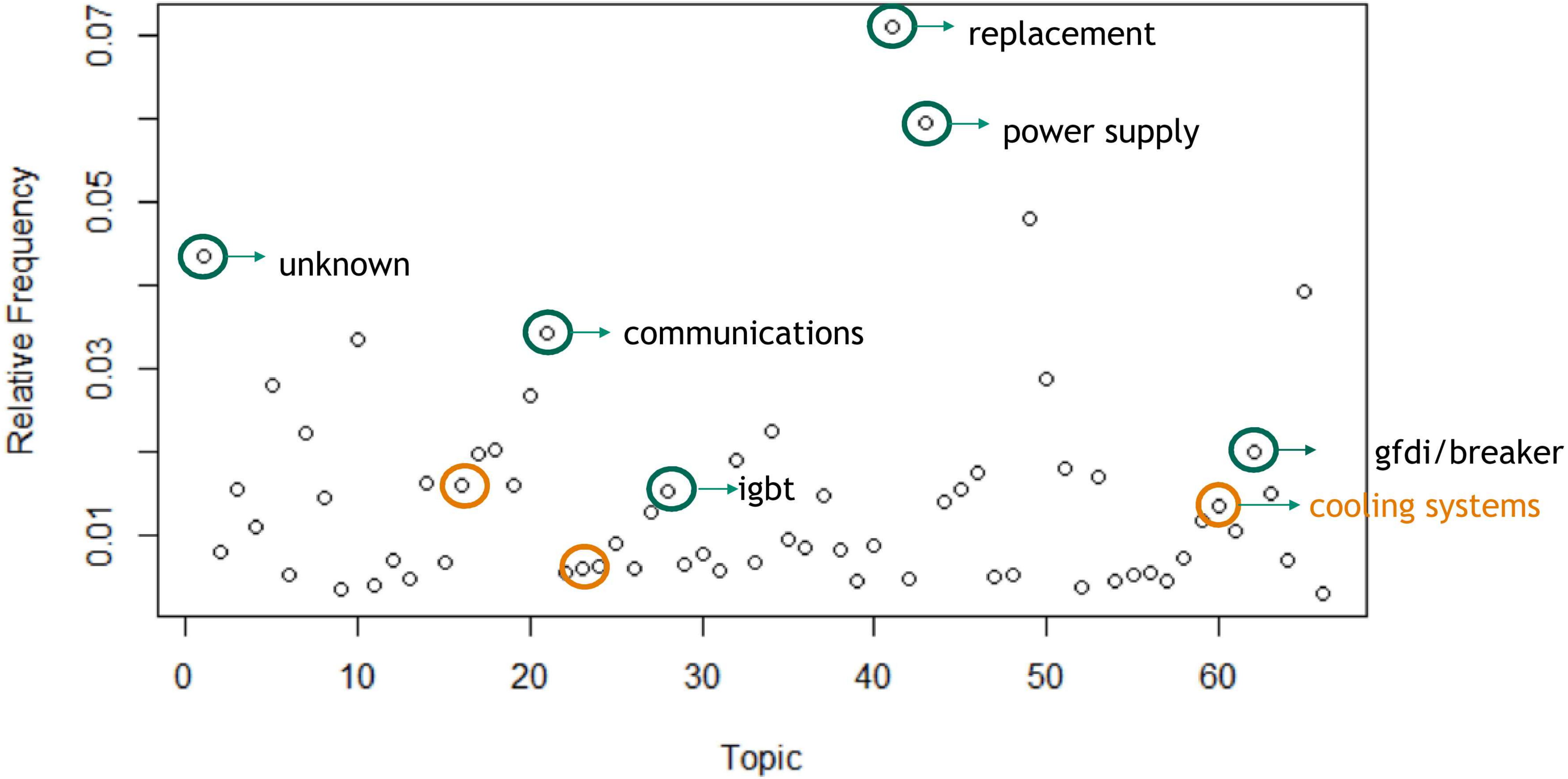
power supply

Distribution of topics

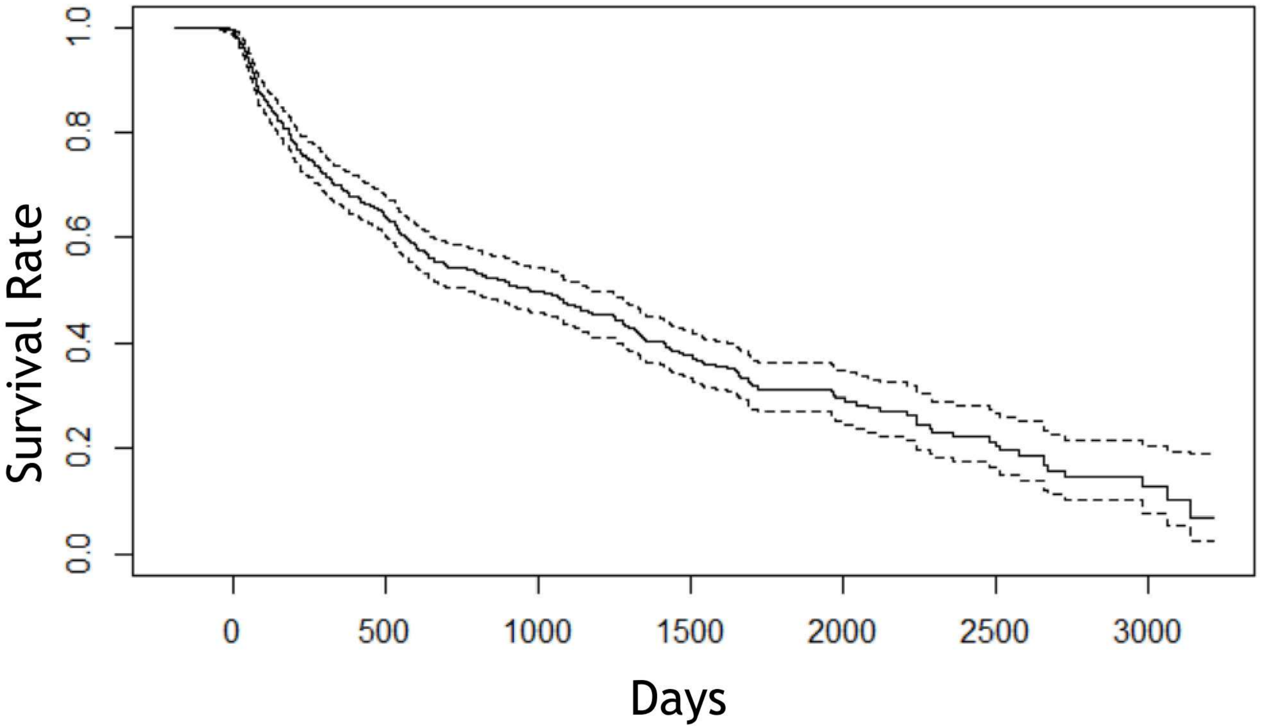


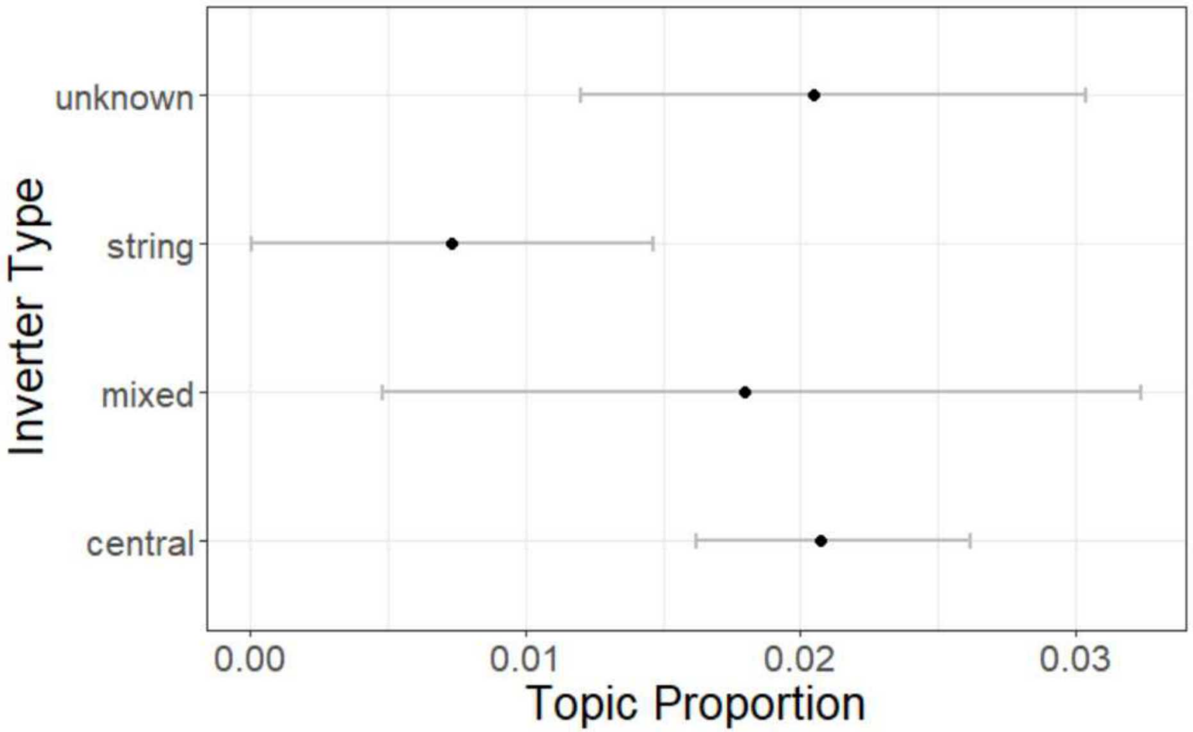
Differences across attributes

Topic Frequency



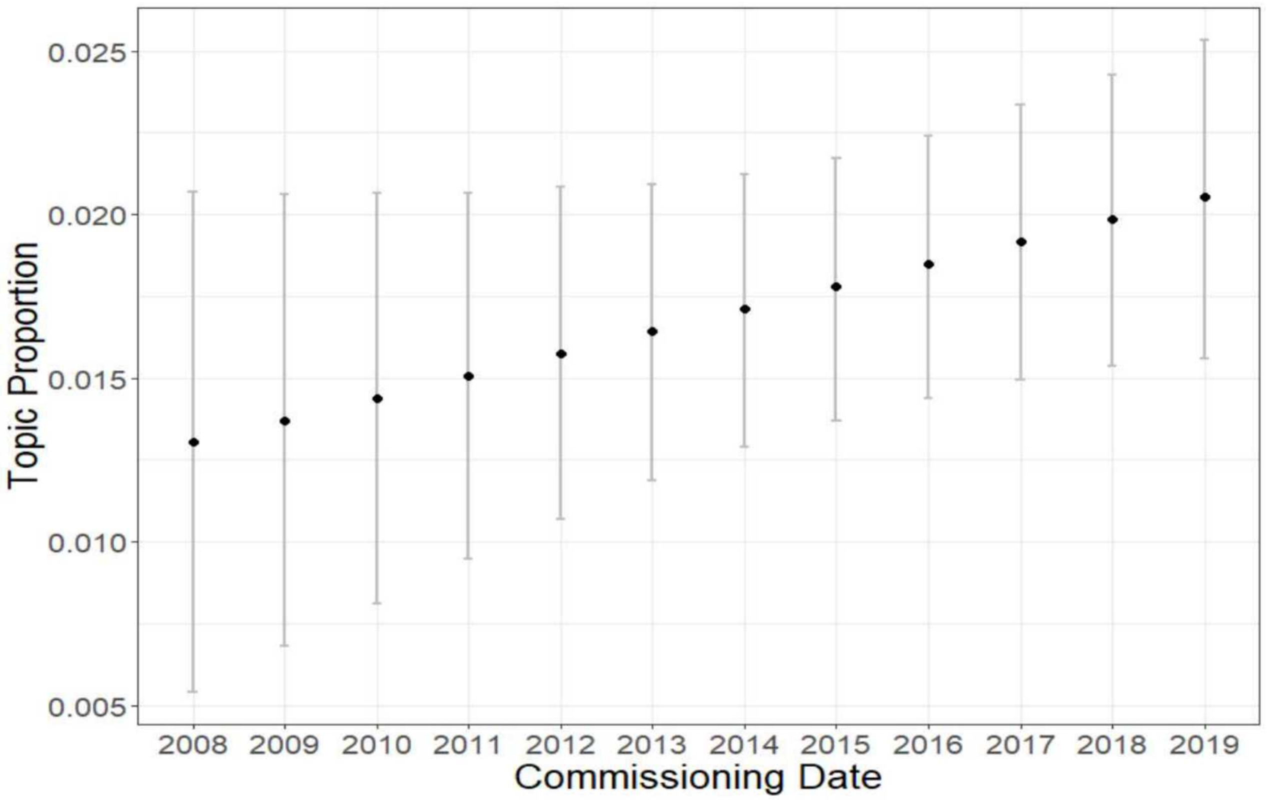
Failure Patterns: IGBTs



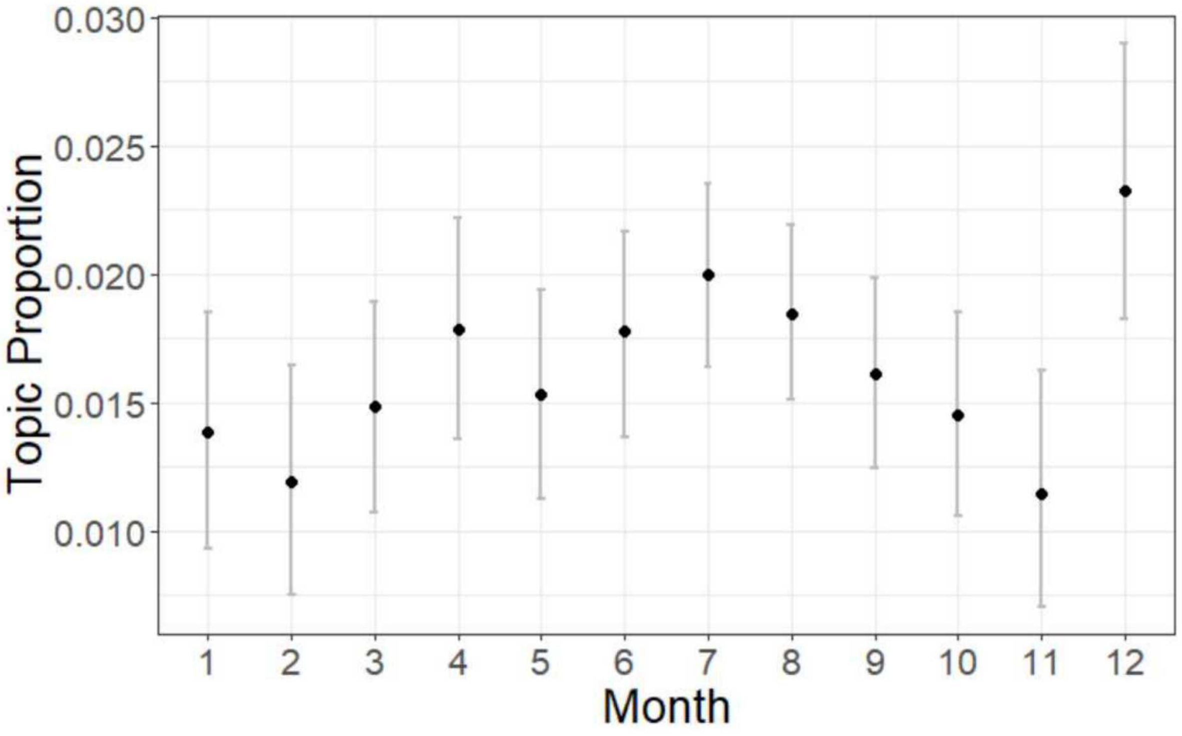


- Within 9 years, almost all sites experience an IGBT failure
- IGBT failures are less prevalent in string inverters than central inverters

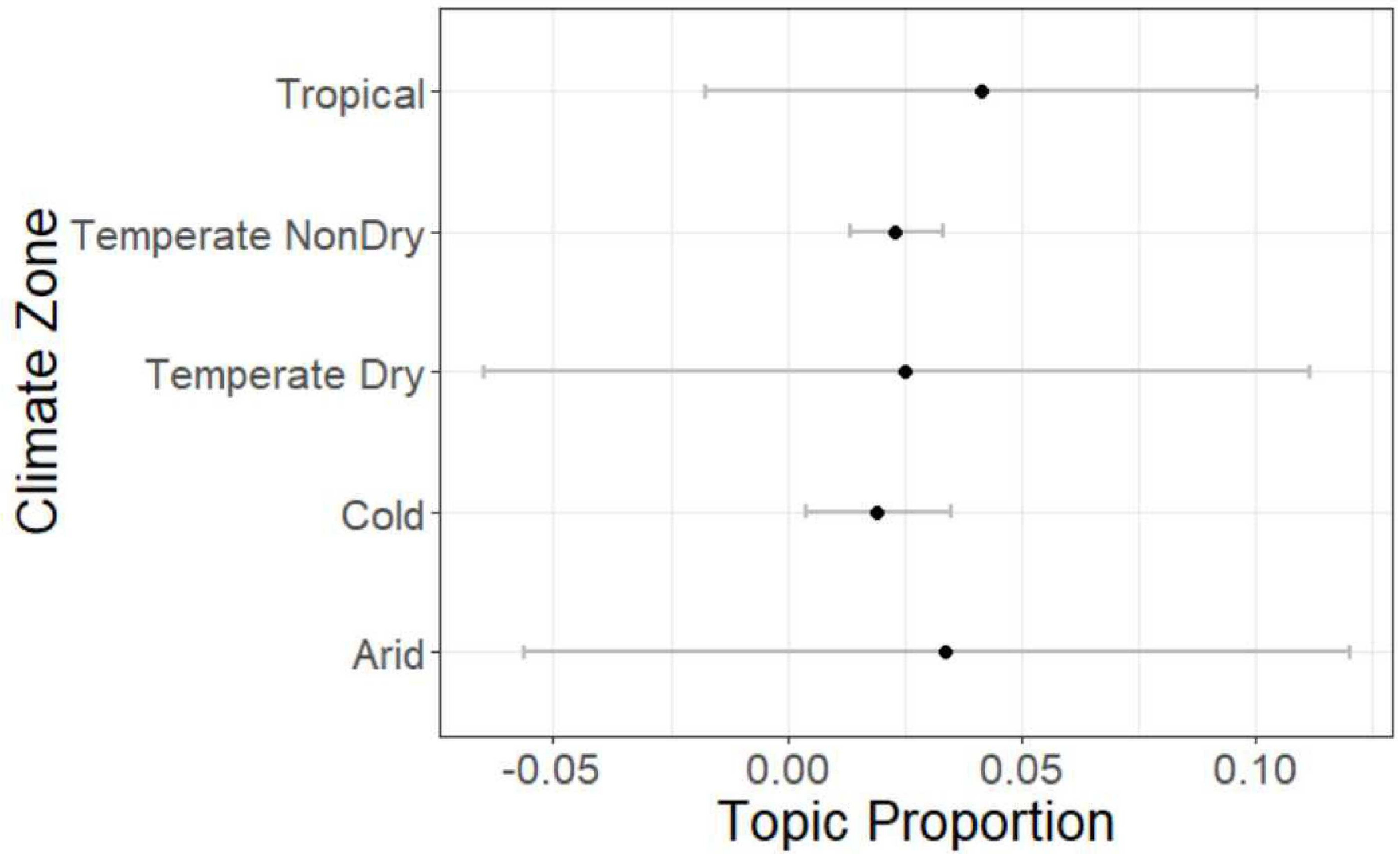
Temporal Variations: Ground Faults/Breaker Trips



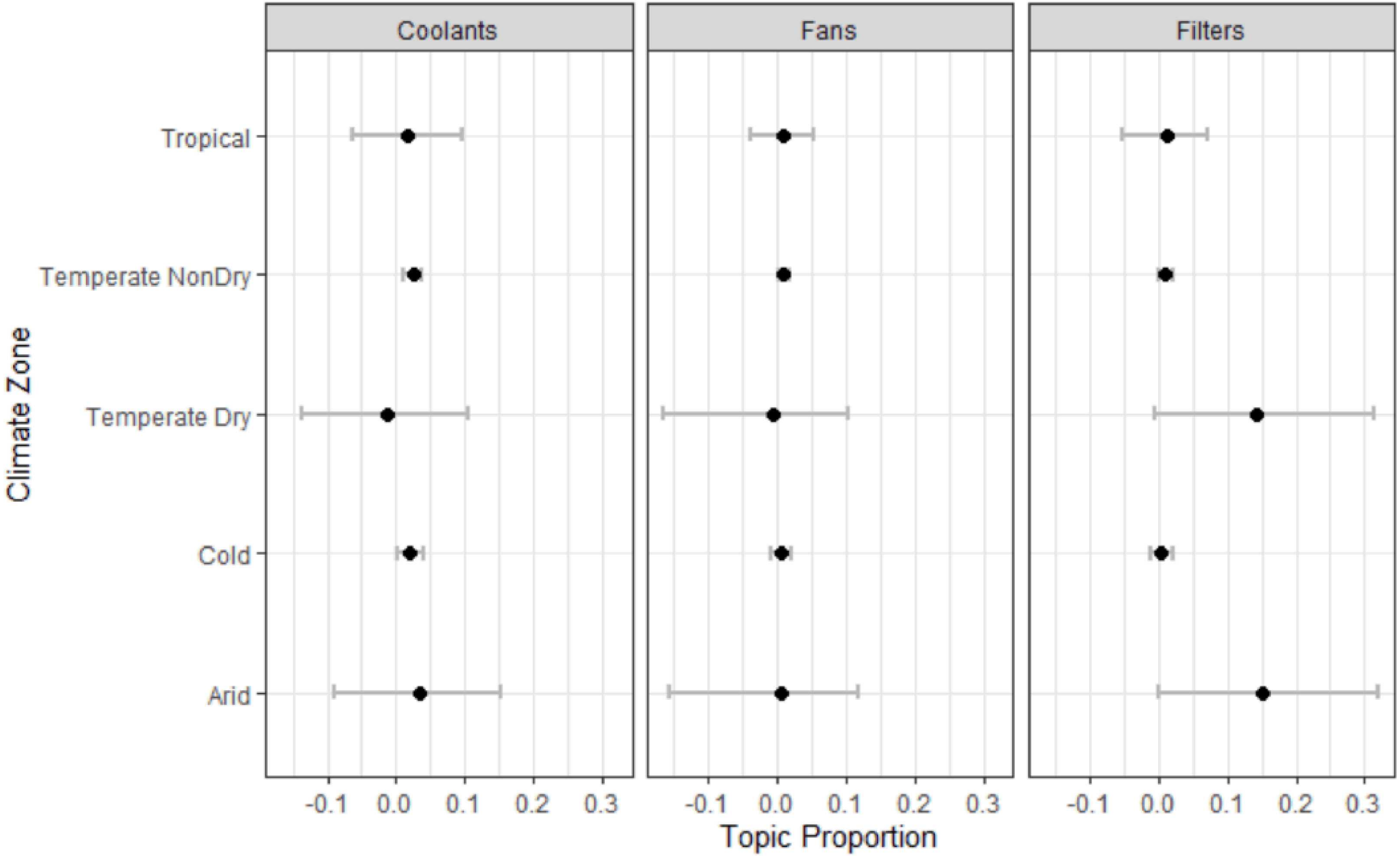
- Increasing prevalence of ground faults in recent years
- Seasonal variations present – financial considerations for Dec peaks?



Geographical Variations: Ground Faults/Breaker Trips



Geographical Variations: Cooling Systems



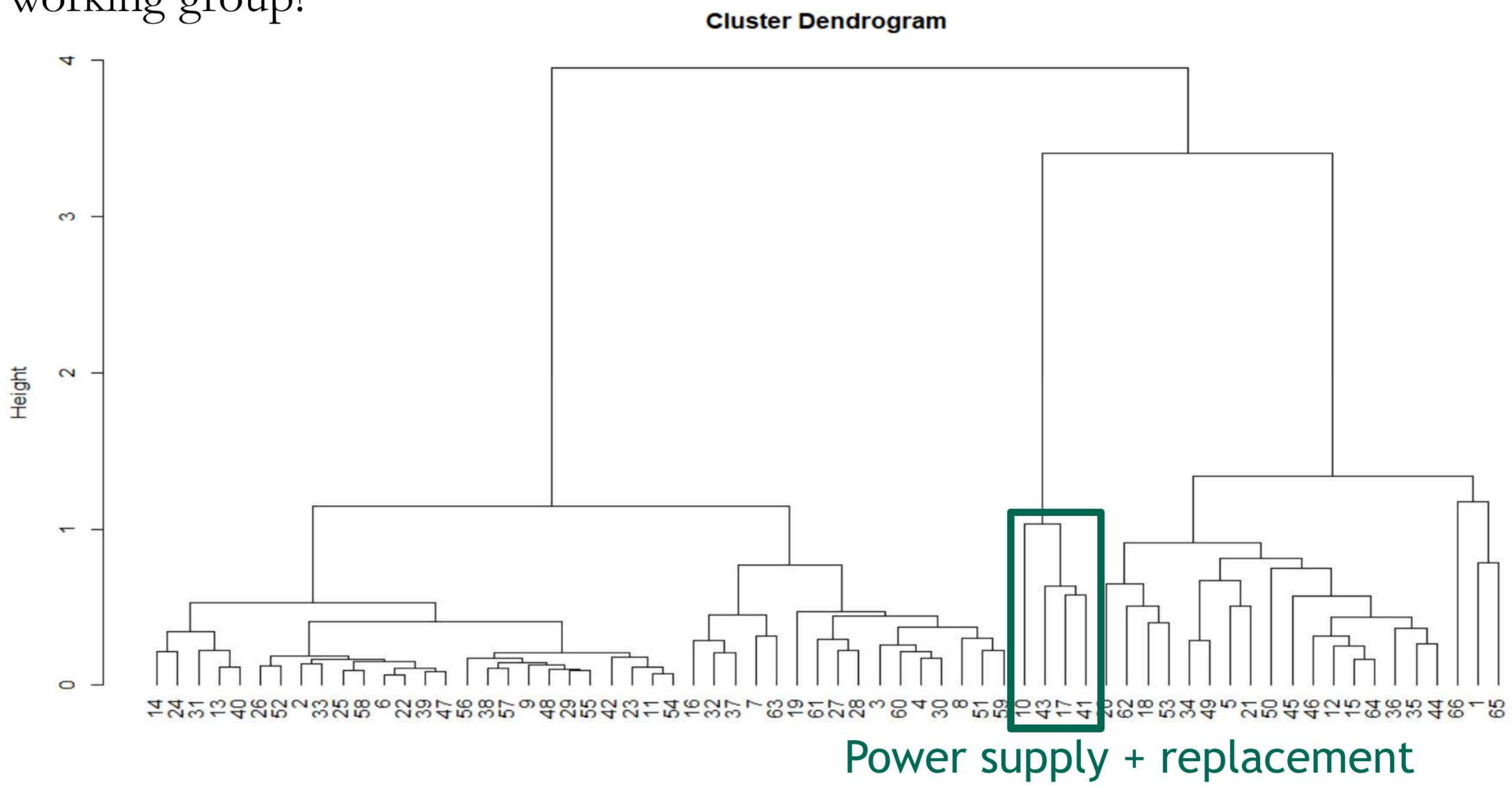
Ongoing work

Are these patterns consistent with your experiences?

Evaluate correlations between topics

Continued discussions standardization is needed (for analysis, for reporting)

Welcome to join our quarterly working group!



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Thank you for your time!

Thushara Gunda

tgunda@sandia.gov