Electricity Networks
Cost structure & Customer Behaviour

Should Network tariffs be

Cost reflective or Value reflective

Pricing Objective

- Optimum Economic Resource Allocation
  - Prices should be set so as to ensure a match between: the incremental economic cost of providing the service and, its incremental value to the customer
  - This ensures that investment in the industry is optimal – not too much, not too little.
- Perception of "fair and equitable"
  - Usually accepted to mean
    - that there are no cross subsidies and
    - that customers pay what it costs to deliver
- Pricing that matches cost delivers both objectives.
- But what does it cost to deliver a Network Service?

Cost Structure

- There are two key drivers of Network costs:
  - The customer's individual location &
  - The customers' collective demand for shared asset capacity
- BUT, not much is variable,
  - Not even in the medium term
- Most Network costs are now "sunk costs"

The Network Pricing Challenge

- Network assets are, with few exceptions, shared assets.

- The key to network pricing therefore is:
  - in understanding the basis on which assets which serve different network functions are shared, and
  - in determining an appropriate basis for sharing the costs of servicing those assets
    - Including a basis for sharing "sunk cost" assets

LRMC and Investment Drivers

- AEMC have decreed LRMC as the basis for Tariff setting
- So, what drives future investment (capital and Opex)
  - New connections, individual and collective
  - The customers' probable (ex ante) collective demand at the various levels of the system
- But "sunk costs" may be as high as 70%
- The three components of cost recovery
  - Connections (Inc. shared) - the driver is spacing
  - Capacity - the driver is collective demand
  - Sunk - there is no driver

Presentation Objective

- Assumed knowledge (DM, AC, PV & Batteries)
- To demonstrate that:
  - The LRMC principal solves only a small part of the pricing challenge
  - The current industry approach of introducing ToU Demand Tariffs is fundamentally flawed and that
  - The use of "market value" is relevant to a regulated monopoly and may well provide the remainder of the solution.

Agenda

- Network Topography
- Network Cost Structure
- Innate Customer Behaviour

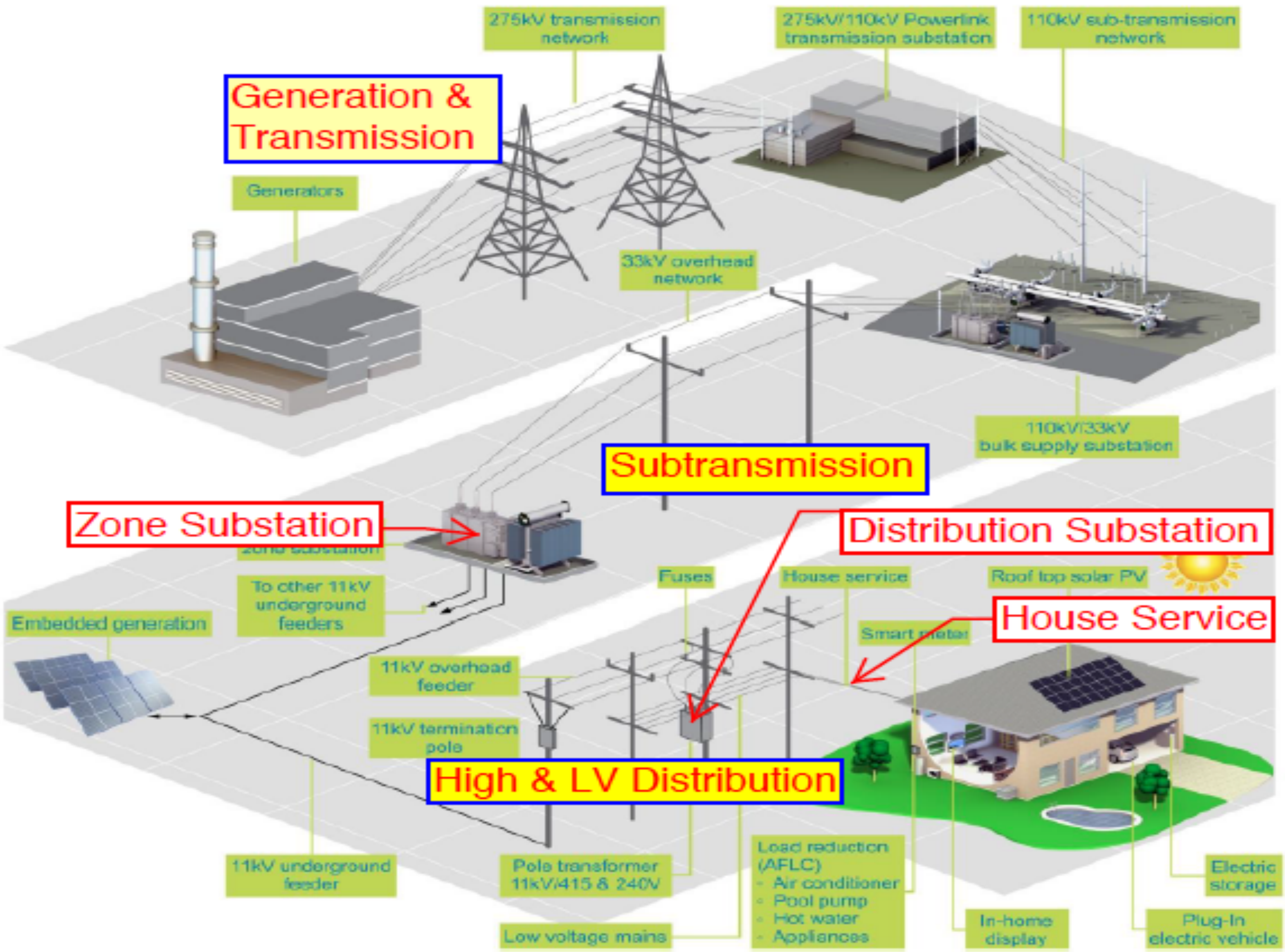
} Cost Reflective Pricing
- Connections
- Capacity
- Sunk Costs

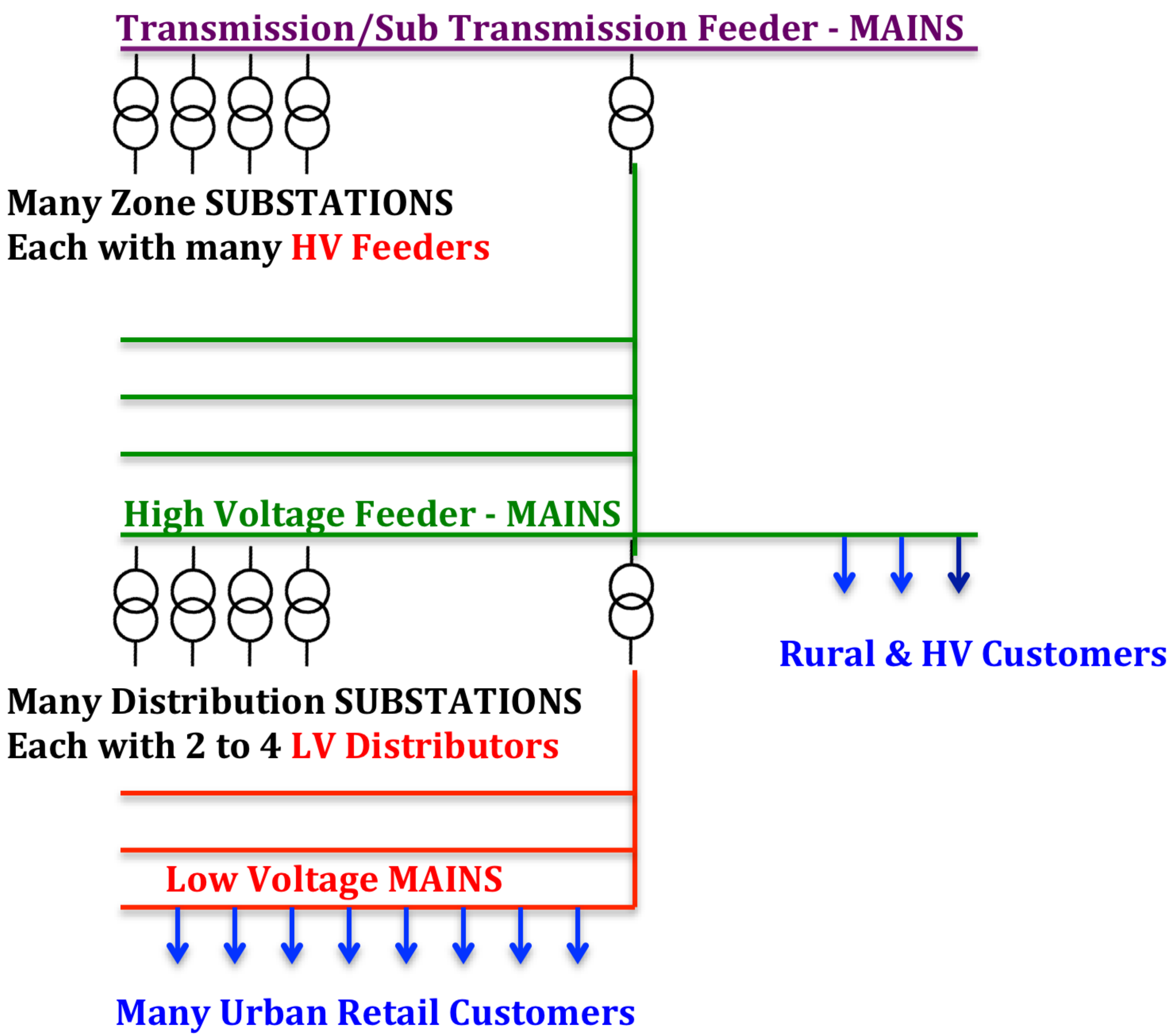
Tariff Options

- Problem with the current Industry approach
  – Some modeling
- Market Pricing in Regulated Monopolies
- Summary & Conclusion

Network Topology

Figure 1 – Typical Electricity Supply Chain





Transmission/Sub Transmission Feeder - MAINS
Many Zone SUBSTATIONS
Each with many HV Feeders
High Voltage Feeder - MAINS
Rural & HV Customers
Many Distribution SUBSTATIONS
Each with 2 to 4 LV Distributors
Low Voltage MAINS
Many Urban Retail Customers

Network Topology

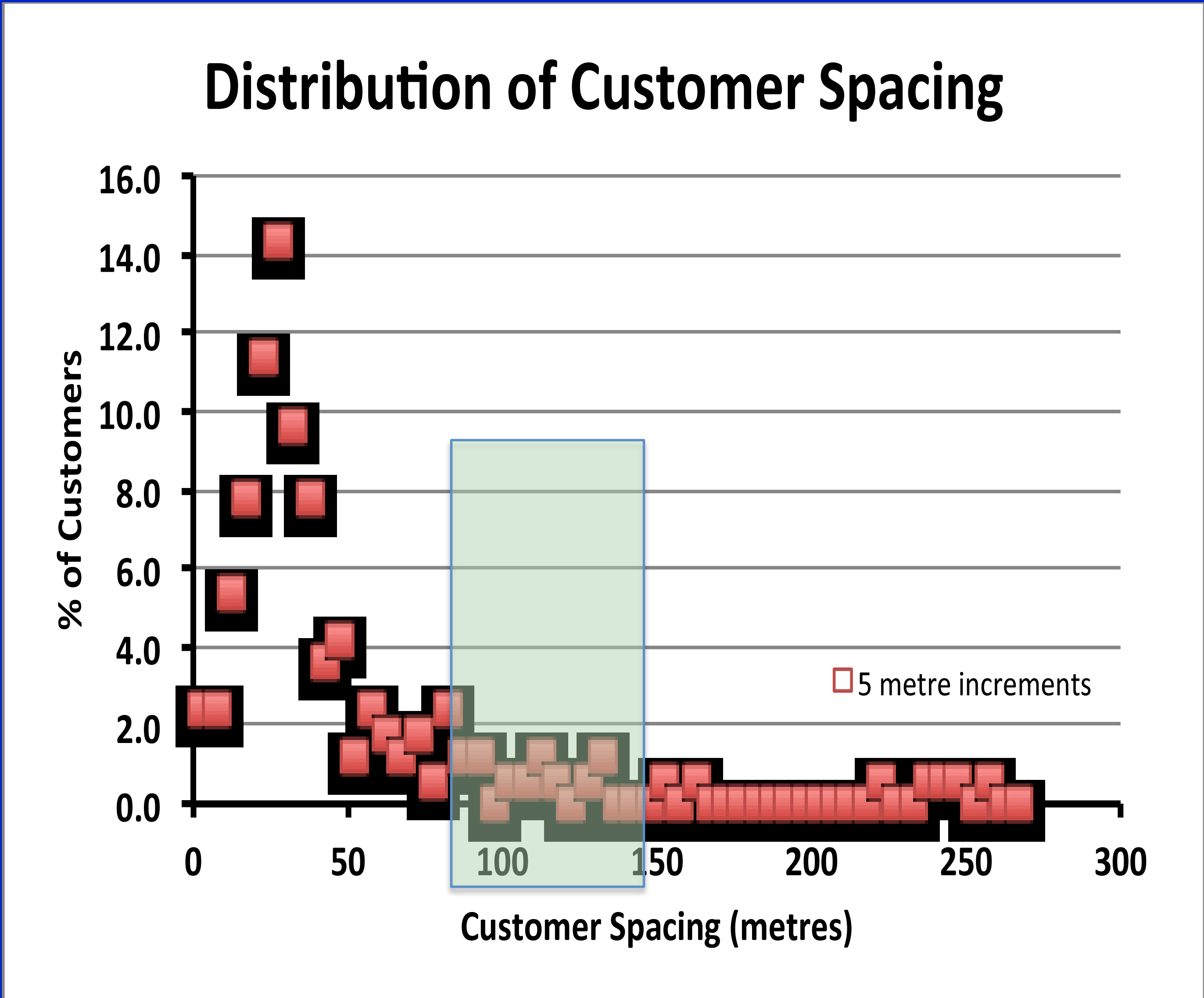
- Multi Leveled
  - Connections 1 customer
  - Street LV Distributor 30/100 customers
  - Distribution Centre 300/500 customers
  - HV feeder 1/2000
  - Zone Substation 20/50000
  - Subtransmission feeders and higher levels
- Spatially Distributed
- Discrete, large "economic increments"

Cost Structure

Cost Structure

- In urban networks
  - Including sunk costs, Less than 50% of costs is driven by demand
  - More than 50% is driven by customer location
- In rural networks
  - Locational costs can be as high as 80% - noting that the customer pays capital contributions
- The spacing between customers drives most of our “poles and wires” cost (both high and low voltage)– regardless of demand

Distance between customers varies widely



Customer Density

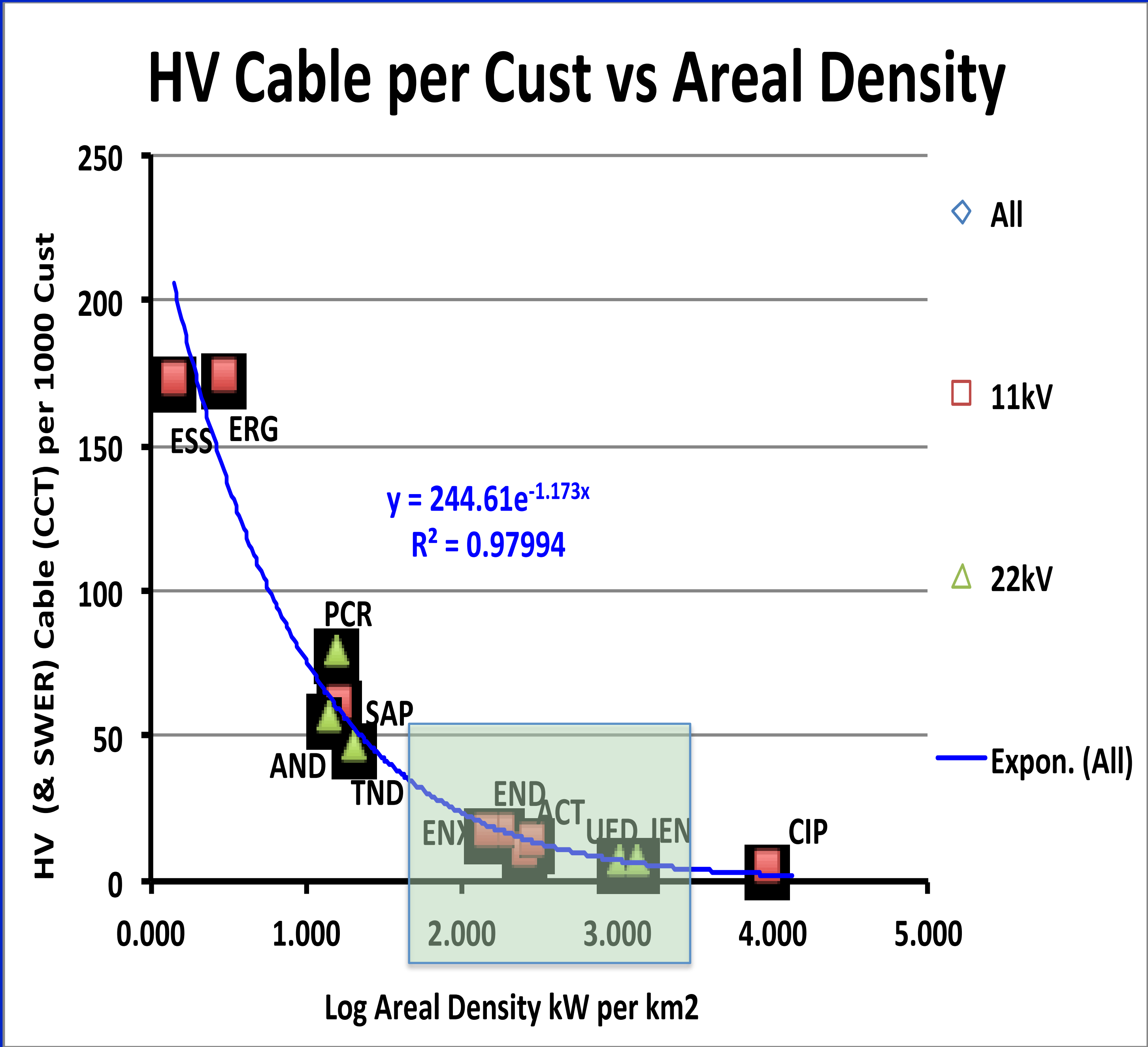
In urban areas low voltage mains per customer varies from 10 to >100 metres.

The quantum per customer is determined by the spacing between customers, regardless of their demand.

They are "shared connection assets"

High Voltage

Customer Density



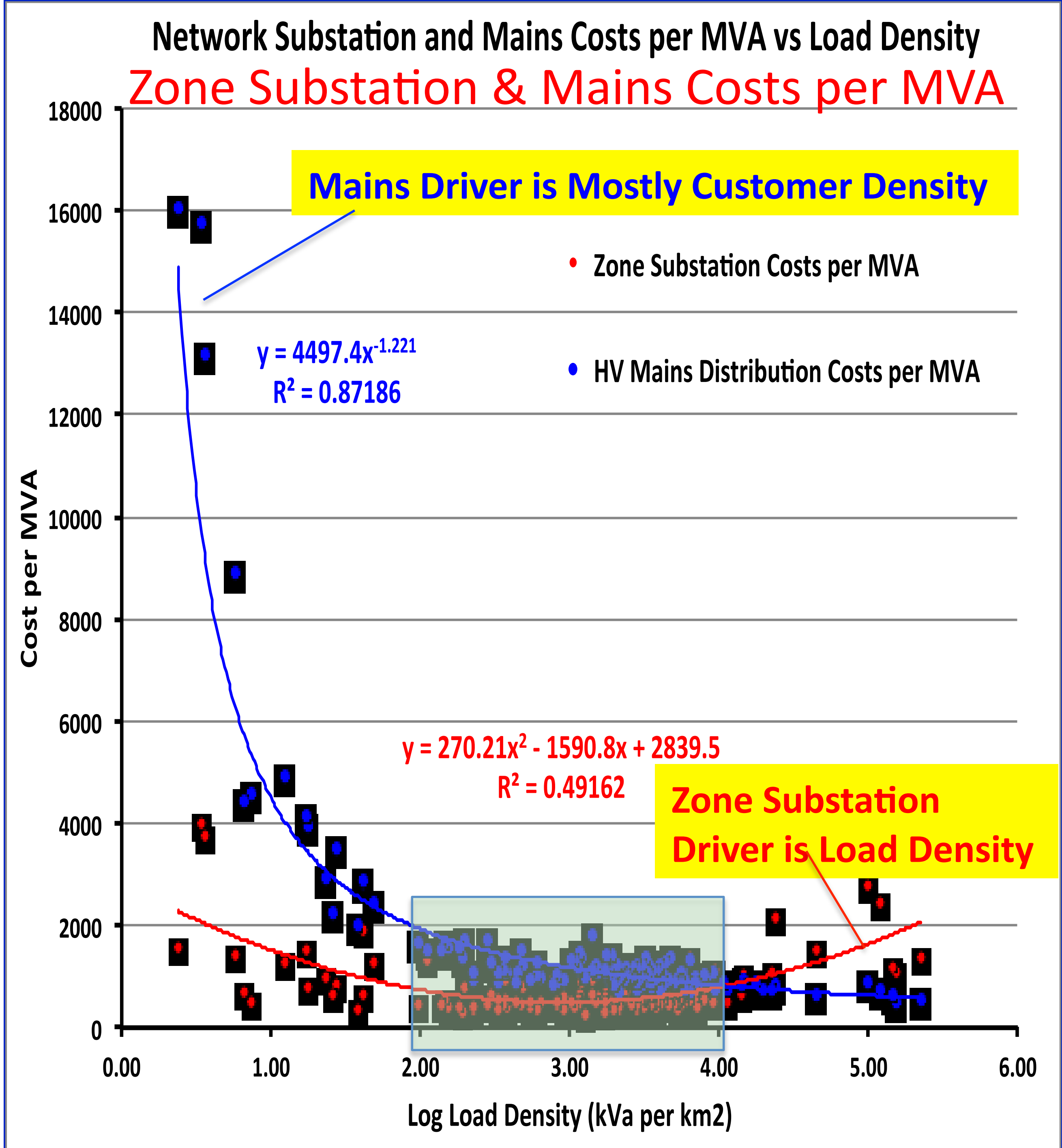
AER RIN data

Demonstrates that irrespective of cable capacity (22kV is double 11kV capacity), HV cable per customer is the same

Mains ("Poles and Wires") Costs

- Mains are what give customers access to Networks Capacity
  - They cost the same, regardless of how much capacity the customer requires
- They are a shared connection asset
  - The quantum being dependent on density
  - The appropriate basis of sharing being premises spacing
- The only asset that is dedicated to the individual customer is the "house service"
- Logically the basis of sharing would be locational

Logically paid as a capital contribution at the time of connection &/or an annuity in perpetuity



HV Mains costs are also driven more by customer density, rather than load density. They are what they are because of the distance between customers. They too are a connections asset

Substation costs are less dependent on density. At high density real estate costs escalate. At low densities, economies of scale are lost. They are capacity assets.

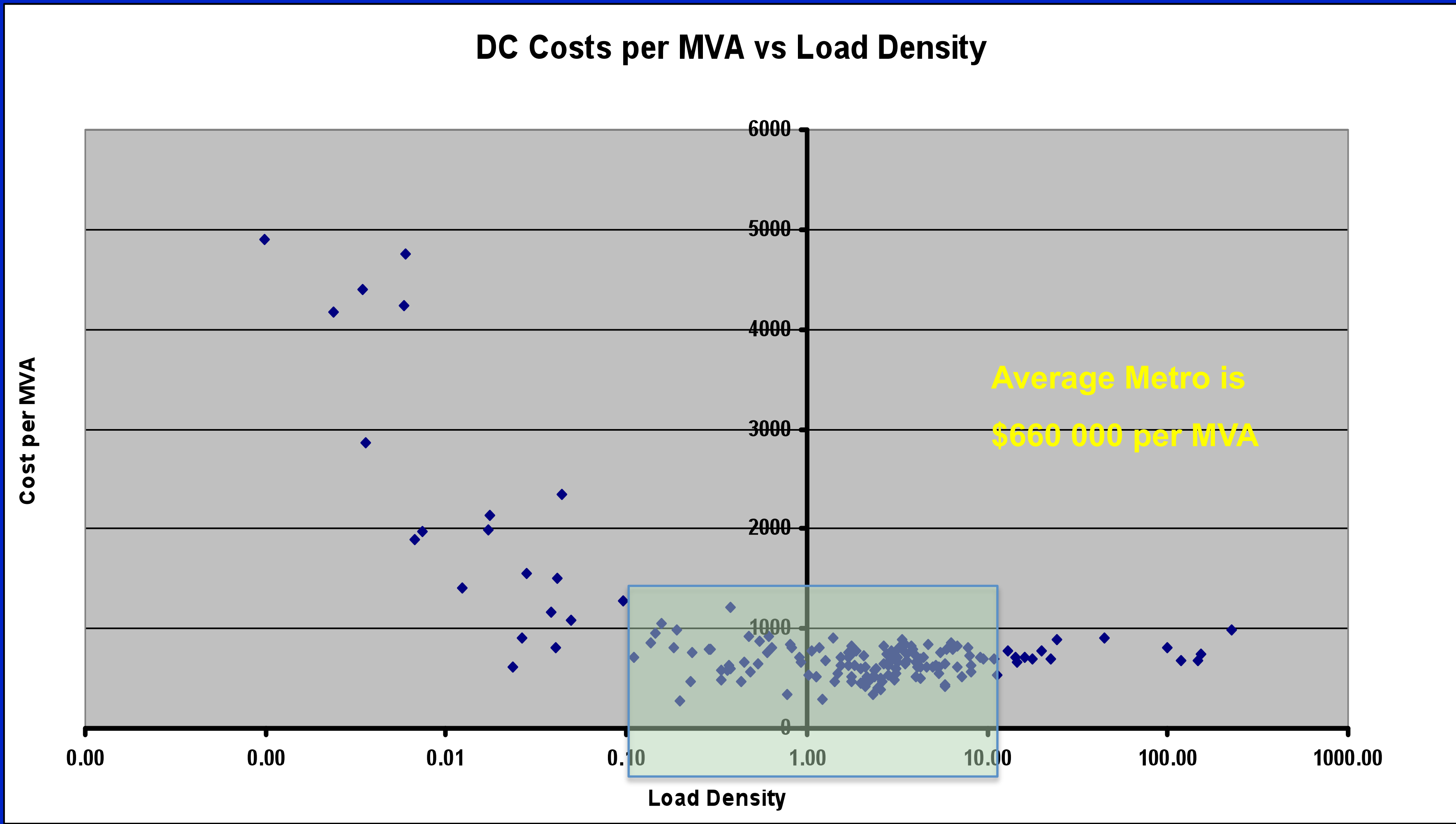
Zone Substation Costs

- Zone Substation costs are less dependent on density, than mains costs
  - And are relatively uniform ($/MVA) over urban densities
  - At high density real estate costs escalate. At low densities, economies of scale are lost.
- They are capacity assets.
  - Built to meet the collective demand of the area they serve.
  - But augmented in large economic increments (typically 50%), so LRMC is spatially variable
    - In areas of high growth they are high, in areas of low growth low.

Logically paid for through some some sort of capacity usage charge (reflecting contribution to the collective demand).

Costs per MVA - Distribution Centres

ACTUAL



Costs appear to have commenced upward trend at higher densities

Distribution Centre Costs

- These too are heavily density dependent
  - At rural densities we require one per customer.
    - They are a dedicated connection asset
  - At low urban densities
    - Networks are voltage constrained, their number is determined by customer spacing. Their capacity will vary, but their cost is largely independent of capacity
    - They are a shared connection asset
  - At high urban densities,
    - networks are load constrained. Their number depends upon the collective customer load
    - They are a capacity asset
  - For large individual customer they are a dedicated connection asset
    - They are a dedicated connection asset

Cost Structure Summary

- "House Services" are a dedicated Connection Cost
  - Driven by demand, but standardized for mass market
- Mains are a shared Connection cost,
  - Driven by customer numbers & spacing – not demand
- Distribution Centre costs
  - Sometimes dedicated (rural and large customer), but mostly (urban residential) shared ARGUABLY the driver of these costs is location more so than demand.
- Zone (and higher system level costs) are shared capacity costs
  - but driven by customers' collective demand

Cost Structure Summary (Cont.)

- To achieve cost reflective pricing:
  - Both dedicated ("House Services") and shared connections (mains & most DC) costs would be recovered through
    - Capital contributions &/or an annuity in perpetuity
  - Capacity (some DC, Zone Substation, & higher system) costs would be recovered through
    - some "sort of" capacity usage charge??
- Sunk costs, economists tell us should be recovered in "non distortionary ways"??

The Challenges of LRMC

- The LRMC principle really only applies to capacity related costs
  - recoverable through usage charges
- Long run capacity costs, because of the lumpy nature of network capacity investment, are highly spatially variable
  - Low in areas of low growth or that have recently been augmented
  - High in areas of high growth or in need of augmentation
- Theoretical economists would like to see these applied as spatially variable "congestion charges", BUT
  - The jurisdictions insist on uniform tariffs.

What "sort of" Capacity Usage

- Networks are designed ex ante, based on the forecast collective demand

- Probable collective demand is therefore the investment driver.

- What matters is the customer's probable contribution to collective demand,
  - not this years or last years actual demand.

Ex ante Demand

If x_i are random variables, and if:

$$y = \sum_{\text{all } i} x_i$$

Then:

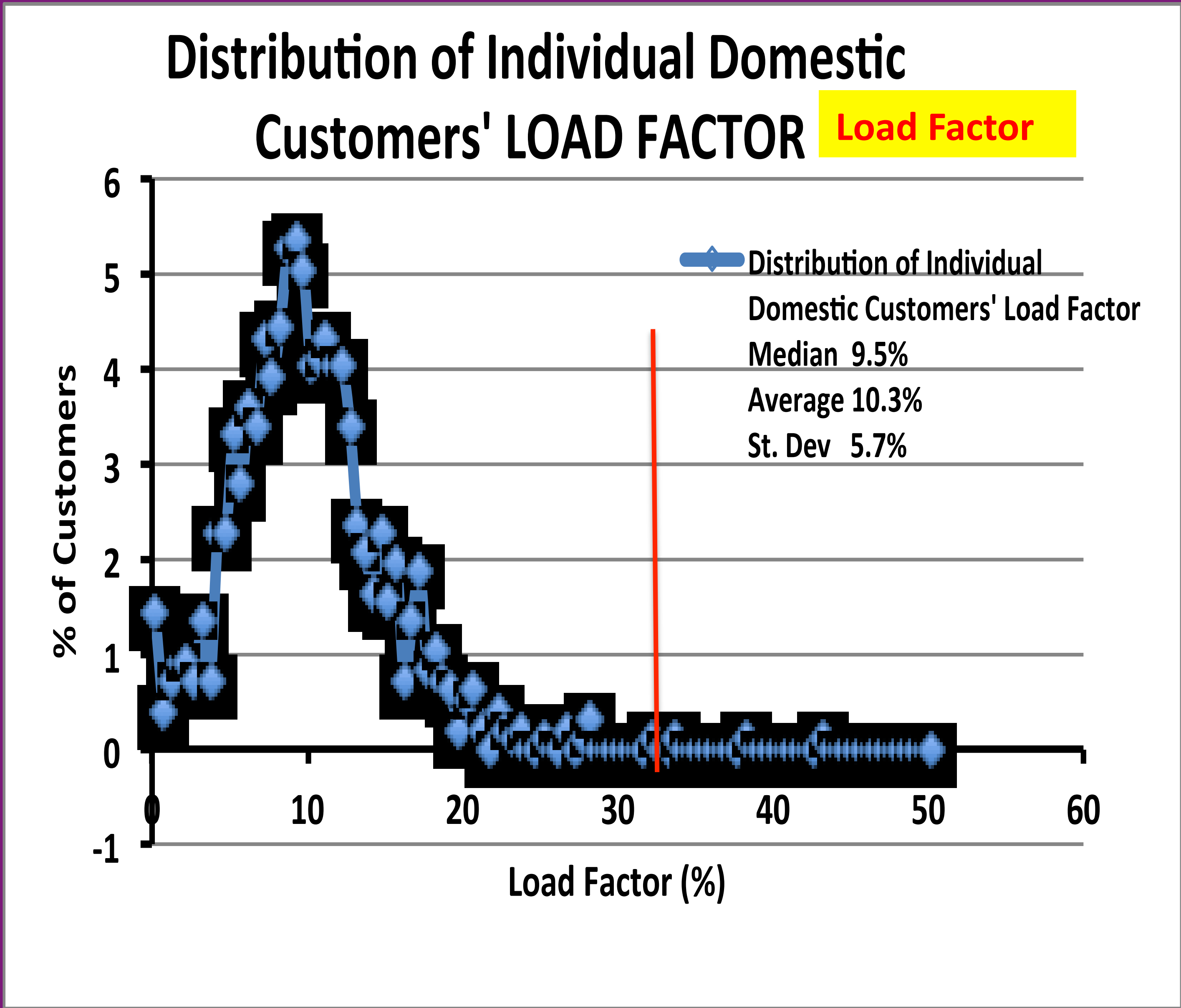
$$\mathcal{E}\,[\,y\,] = \sum_{\text{all } i} \mathcal{E}\,[\,x_i\,]$$

Where $\mathcal{E}$ is the expected value

To understand the implications of this we need to look at and understand "Innate customer behaviour".

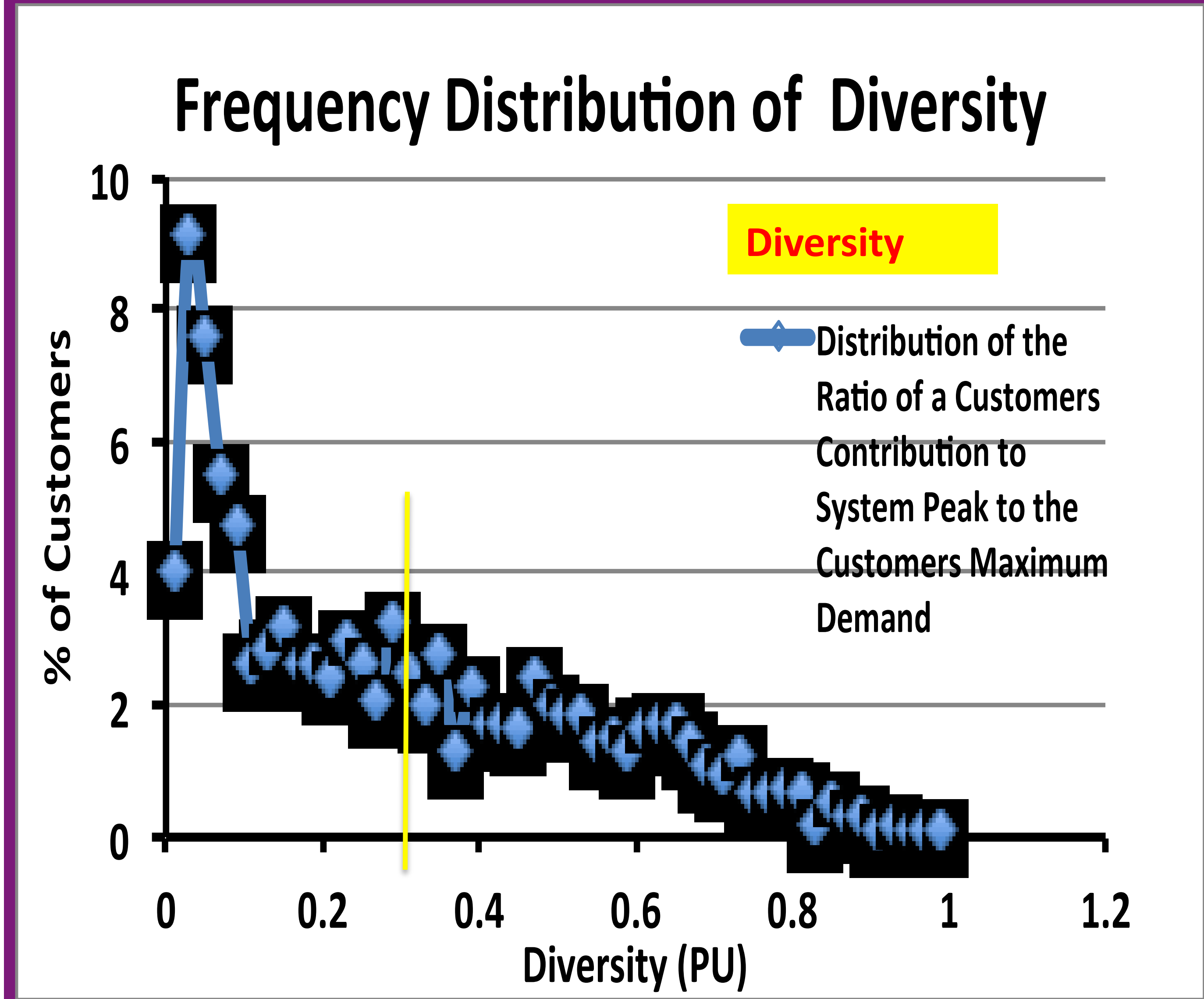
Innate Customer Behaviour

Individual Customer Load Factors Vary Widely



- **Load Factor is the Ratio of Average Demand to Maximum Demand**
- **It is a measure of how effectively consumers individually use network capacity**
- **Collectively the domestic Load Factor is @ 35%**
- Solar Cities Data

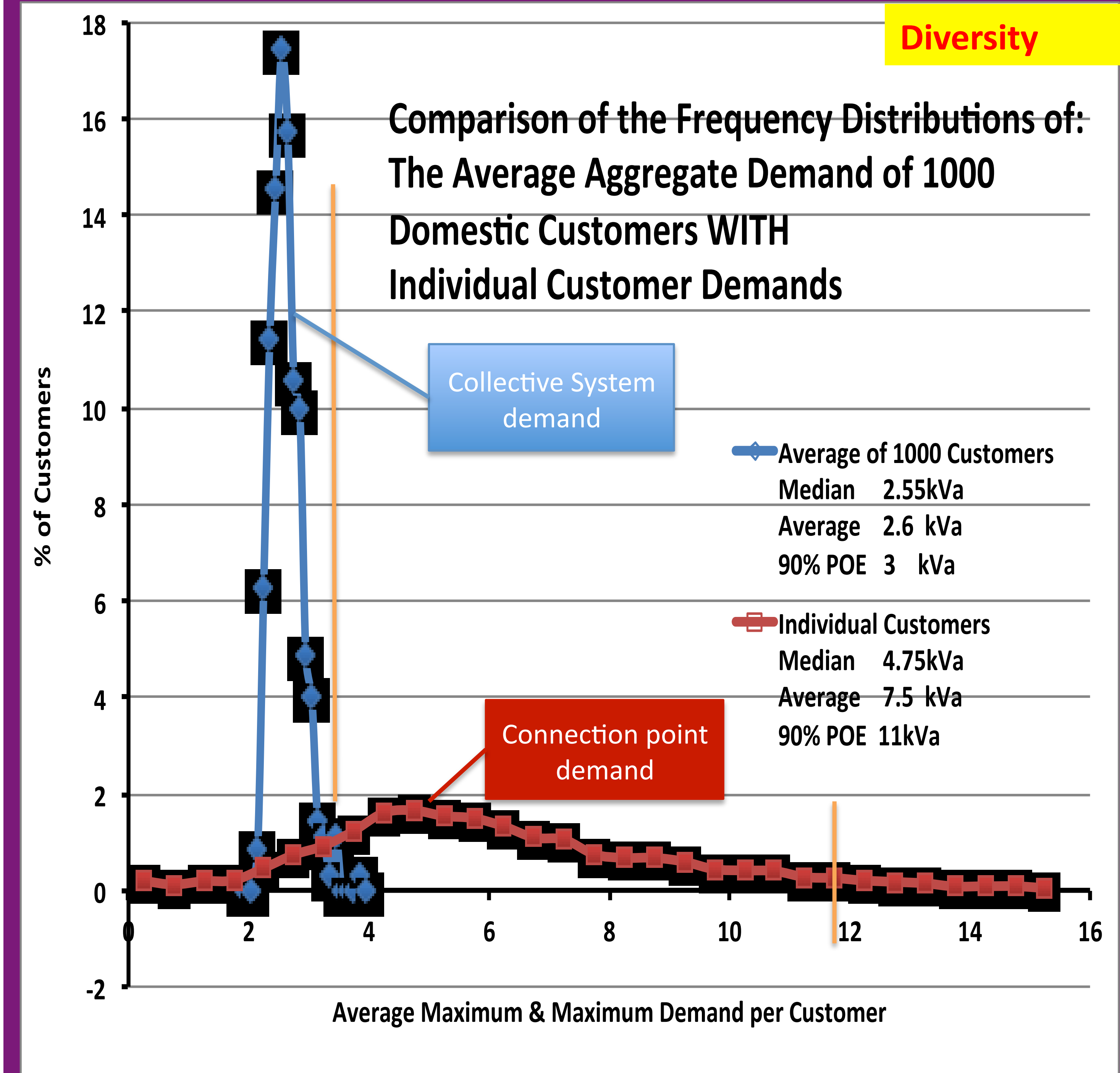
Individual Customer Diversity Varies Widely



- Diversity is the Ratio of a customers contribution to collective demand (System Peak) to his individual Maximum Demand
- 50% of customer have diversities < 25%
- 25% <8%
- Average diversity is 0.31
- Solar Cities Data

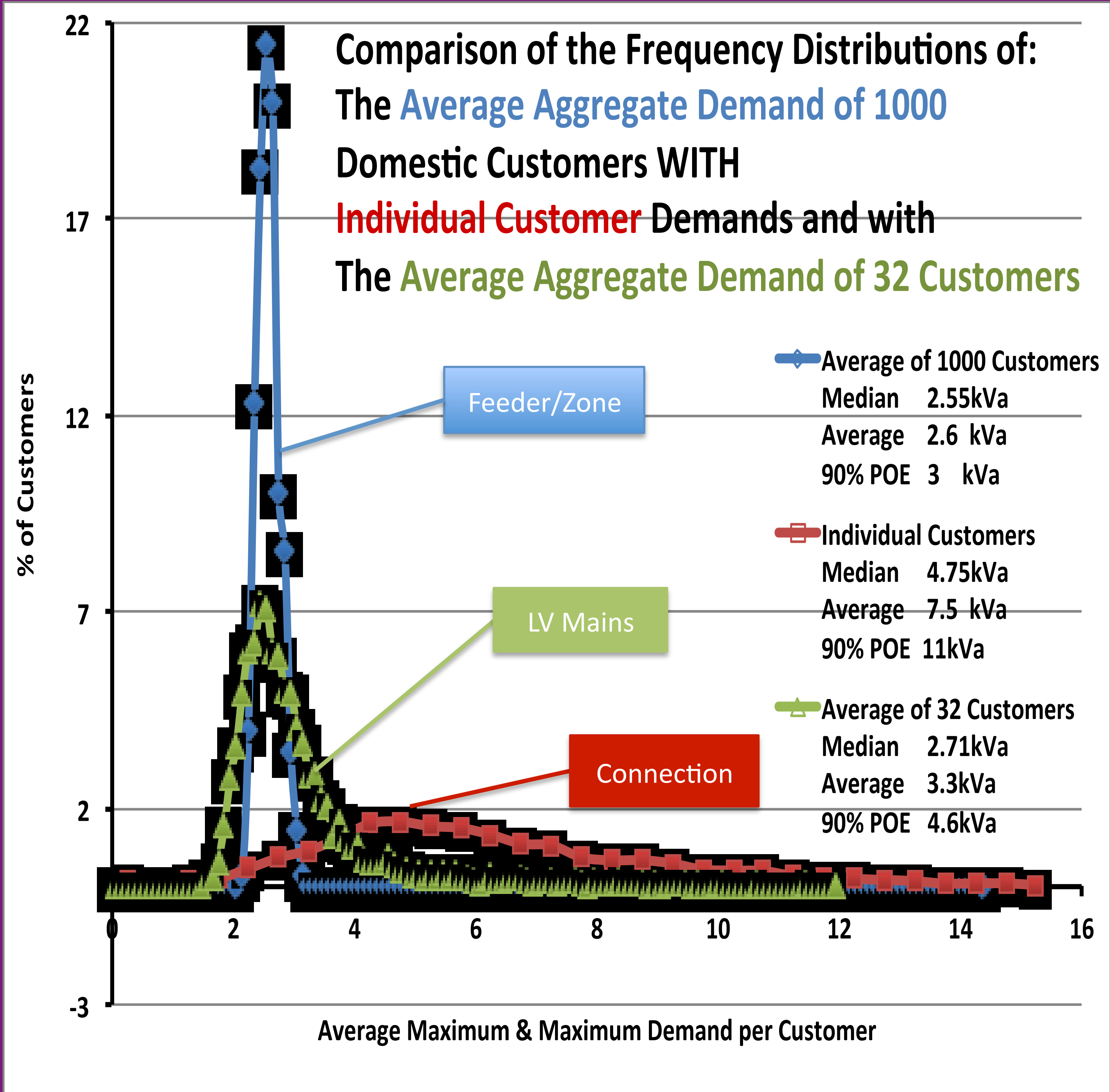
Because innate individual customer behaviour is stochastic:

Collective behaviour is very different to individual behaviour



- Average individual demand is 3 times collective demand
- We Build for the collective demand - POE 10%
- Stand alone requires almost 4 times the capacity
- We can measure the blue BUT Customers understand RED

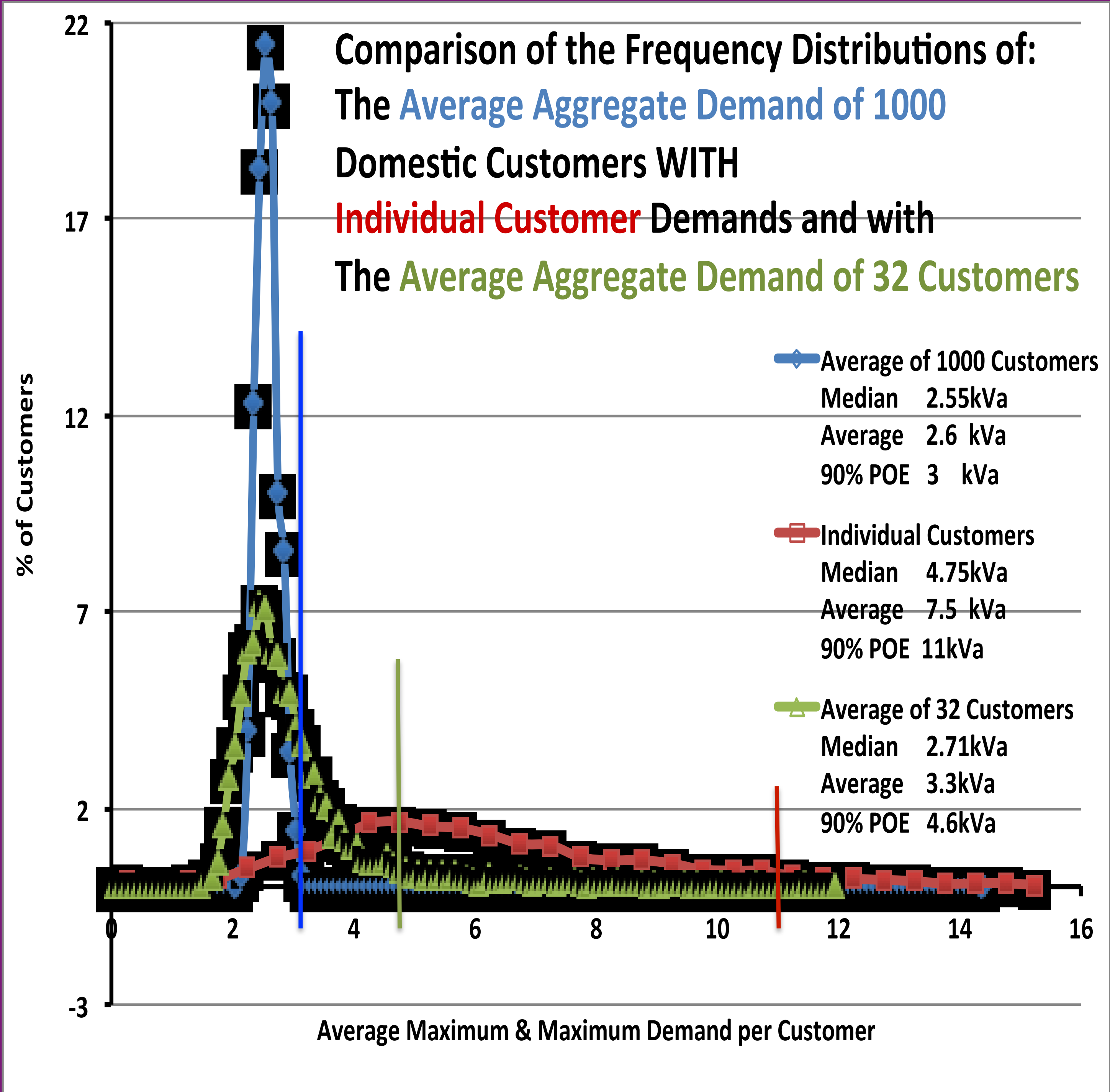
SGSC data



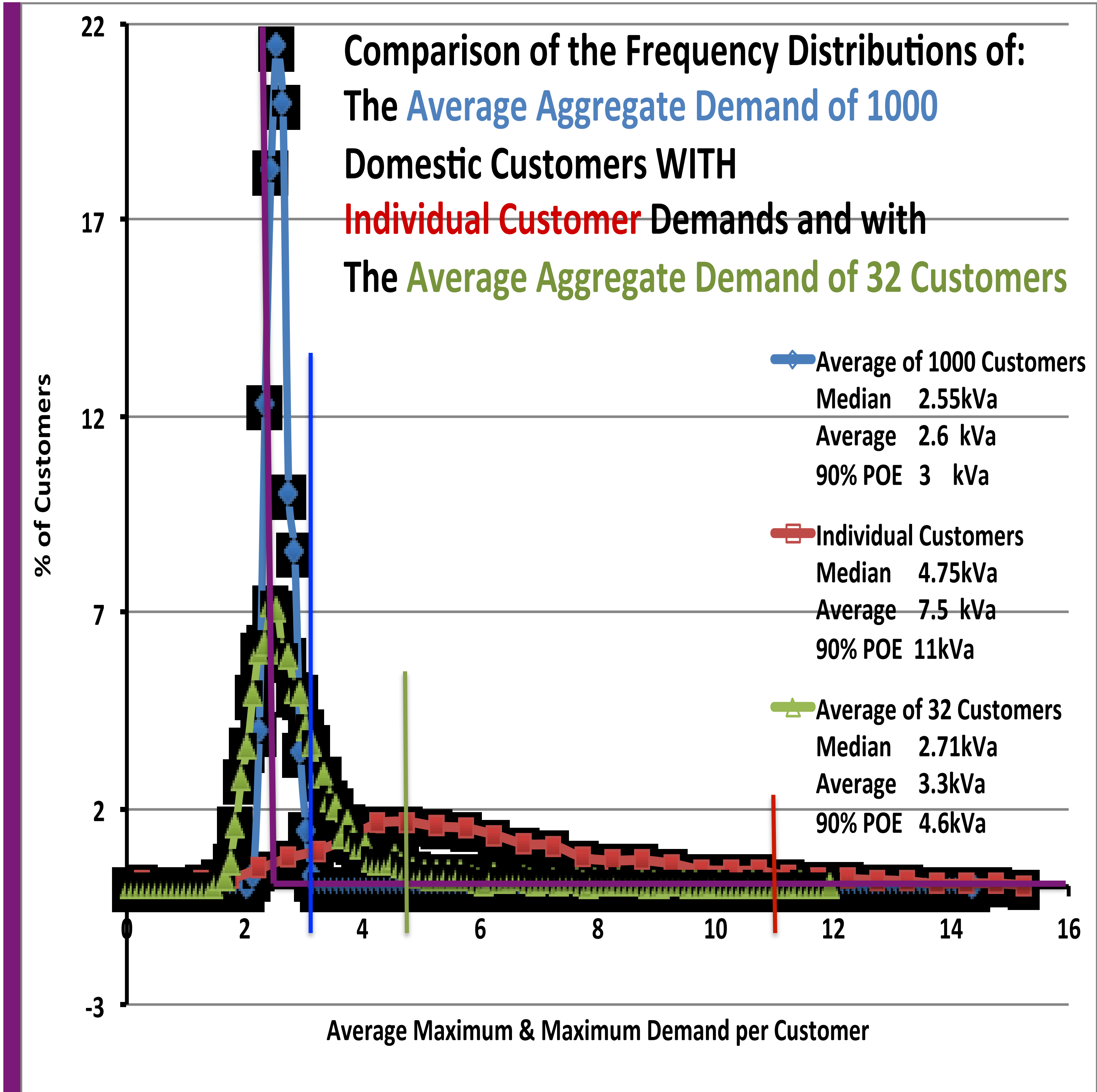
NETWORK LEVELS

Same chart as previously, but with "aggregate of 32 customers" added

32 has been chosen because it is the lowest level of aggregation – 1ϕ LV Mains



10% POE lines have been added



The purple lines represent the frequency distribution of the average aggregate of millions of customers

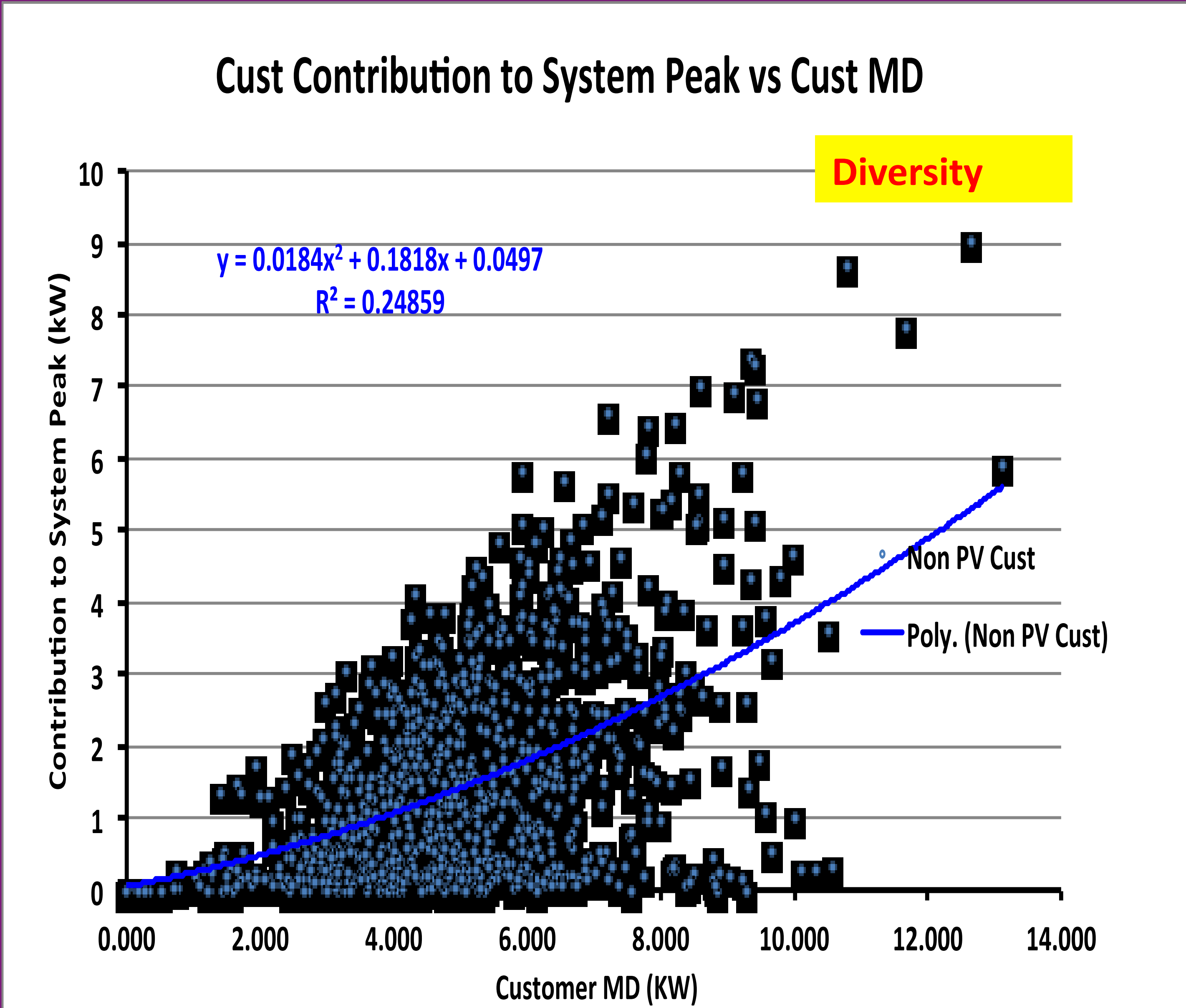
– all values reduce to @ 2.5kVa

What should we Measure and Charge for?

- It is the collective customers' demand that: drives the need for capacity and therefore, drives capacity costs.
- We can measure (and base charges on) the customers contribution to the collective maximum demand.
  - But customers can't know when the collective maximum will occur and will feel disempowered
- Alternatively we can measure and charge for customers connection point demand
  - But unfortunately connection point demand is a poor surrogate for contribution to collective demand.
- It all depends on how we measure demand.

The Problem with Connection Point Demand Tariffs

Anytime Demand



Individual Customer Demand is a poor surrogate for contribution to upstream collective (system peak) demand

Solar Cities Data

Diversity

Does Actual Contribution to System Demand Actually Drive costs?

Arguably Not!

- Networks are designed ex ante, based on the forecast collective demand

- So what matters is the customers probable contribution to collective demand, not actual

Here we need to distinguish and understand the difference between the purely random and the systemic differences between customers profiles

- The vast majority of the differences between customers' load profiles is purely random.
  - Which is why the collective demand per customer is so much less than the individual demand
- We need do nothing (indeed should do nothing) to manage purely random variations
  - Such as whether a customer happened to be at home or not, or entertaining or not, at the time of the peak
- Instead focus on the systemic differences, such as
  - whether the customer has an AC or not
  - Whether he has a particular mix of appliances and typical usage patterns that would see appliances being used concurrently at peak times
- THE IMPLICATIONS OF THIS RANDOMNICITY ARE TWOFOLD?

Firstly:

In my Opinion

- Average demand, during periods of potential peak demand is more likely to be a reliable indicator of the systemic capacity requirement, than any measure of actual demand

Secondly:

- There is no merit in attempting to apply DM to the purely random components of a customers demand
  - reducing a customers demand by a factor of 3, achieves no benefit if it produces identical load profiles for all customers
  - the collective demand will be UNCHANGED
- DM, to be effective, must be aimed at shifting demand completely away from periods of potential peak demand
- DM applied at times of other than potential peak, is a waste

The Problem with Demand Tariffs

- **The problem with existing (energy only) network tariffs is that they:**
  - Incentivize perverse customer behaviour, which
  - Results in intra class cross subsidies, which
  - Threaten long term sustainability of the industry, and
  - Result in sub economic utilization of national resources

- **The DNSP industry is currently advocating the introduction of ToU Demand Tariffs for domestic and small business customers.**

- **Unfortunately these new tariffs will simply incentivize a different set of perverse behaviour.**

First Topic

Some Crude Modeling

- **Modeling Framework**
  - 32 domestic residences
  - Identical appliance mix
  - Identical probability of use
  - Identical cycle times
  - Non Time Imperative Appliances only
- **Represents both**
  - 32 customers on a distributer
  - 32 statistical trials of the same customer
- **Load Profile & Tariff**
  - Uniform demand throughout 8 hour peak period

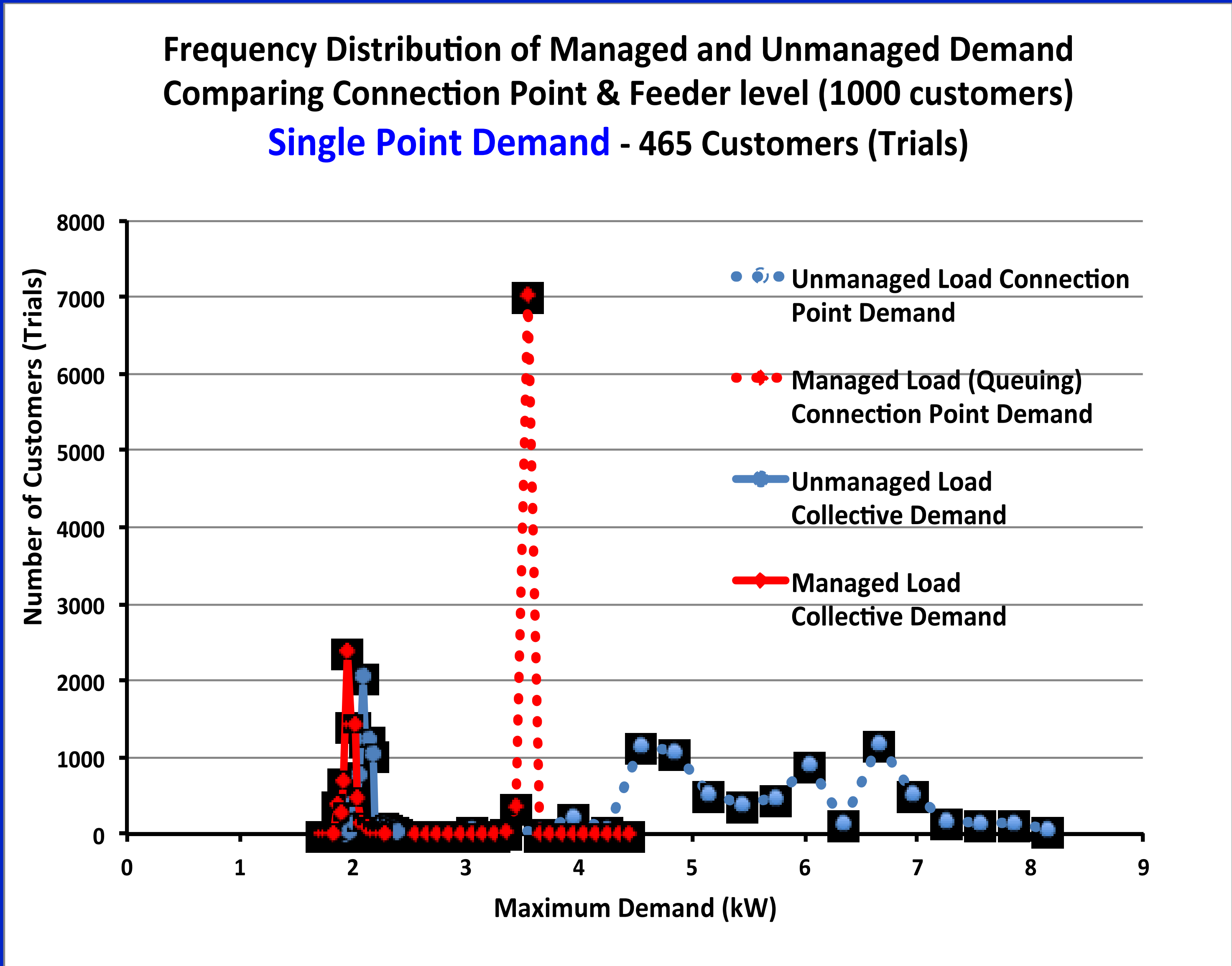
With a load Management System that uses "appliance queuing" to manage down connection point demand.

Modeling Framework

Appliance In Queue priority	Demand kW	Probability Of Use at Peak	Cycle Time Intervals On/Off	Probable Demand kW	Demand Ceiling
Hot Water	3.6	1	1/4	0.72	3.6kW
Refrigerator	0.5	1	2/2	0.25	
Freezer	0.4	1	2/4	0.13	
Dish Washer	1.2	0.5	4/12	0.15	
Cl Washer	0.5	0.3	10/6	0.09	
Cl Dryer	2.1	0.3	5/5	0.32	
Pool pump	0.2	1	16/0	0.20	
Pool Cleaner	0.2	1	16/0	0.20	
PC Chargers	0.1	1	8/8	0.05	
TOTAL	**8.8**			**2.11**	

Non-Time Imperative Appliances, with a 3.6 kW Water Heater

% Connection point demand reduction is 6 times collective reduction



Chargeable demand reduced by 5 to 55 % (average 38%)

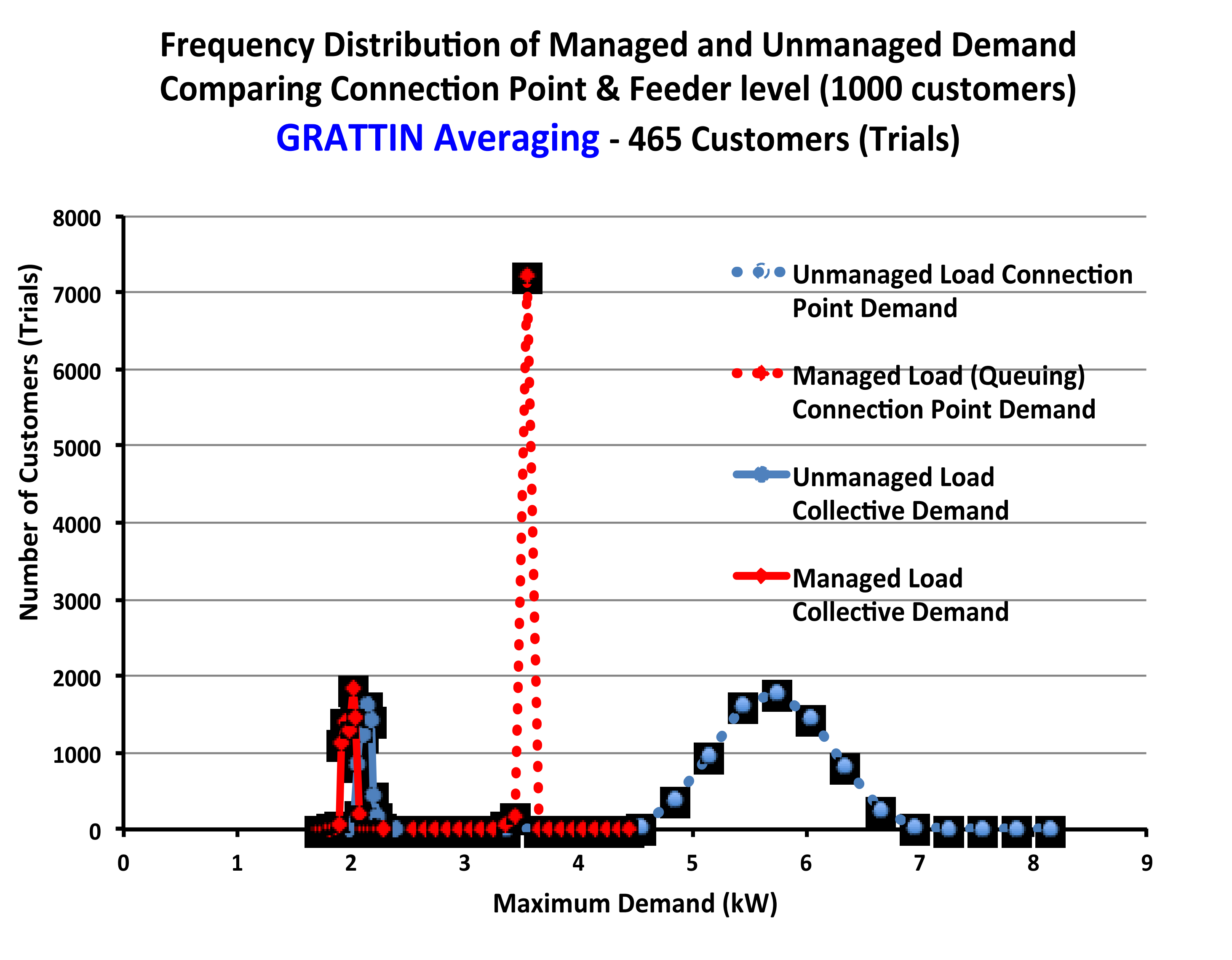
Expected (average across 8 hours) Contribution to collective demand reduced by 6 %

10% POE demand reduced by 9 %

6 % of load shifted beyond the peak period

Non-Time Imperative Appliances, with a 3.6 kW Water Heater

% Connection point demand reduction is 6 times collective reduction



Chargeable demand reduced by 20 to 50 % (average 38%)

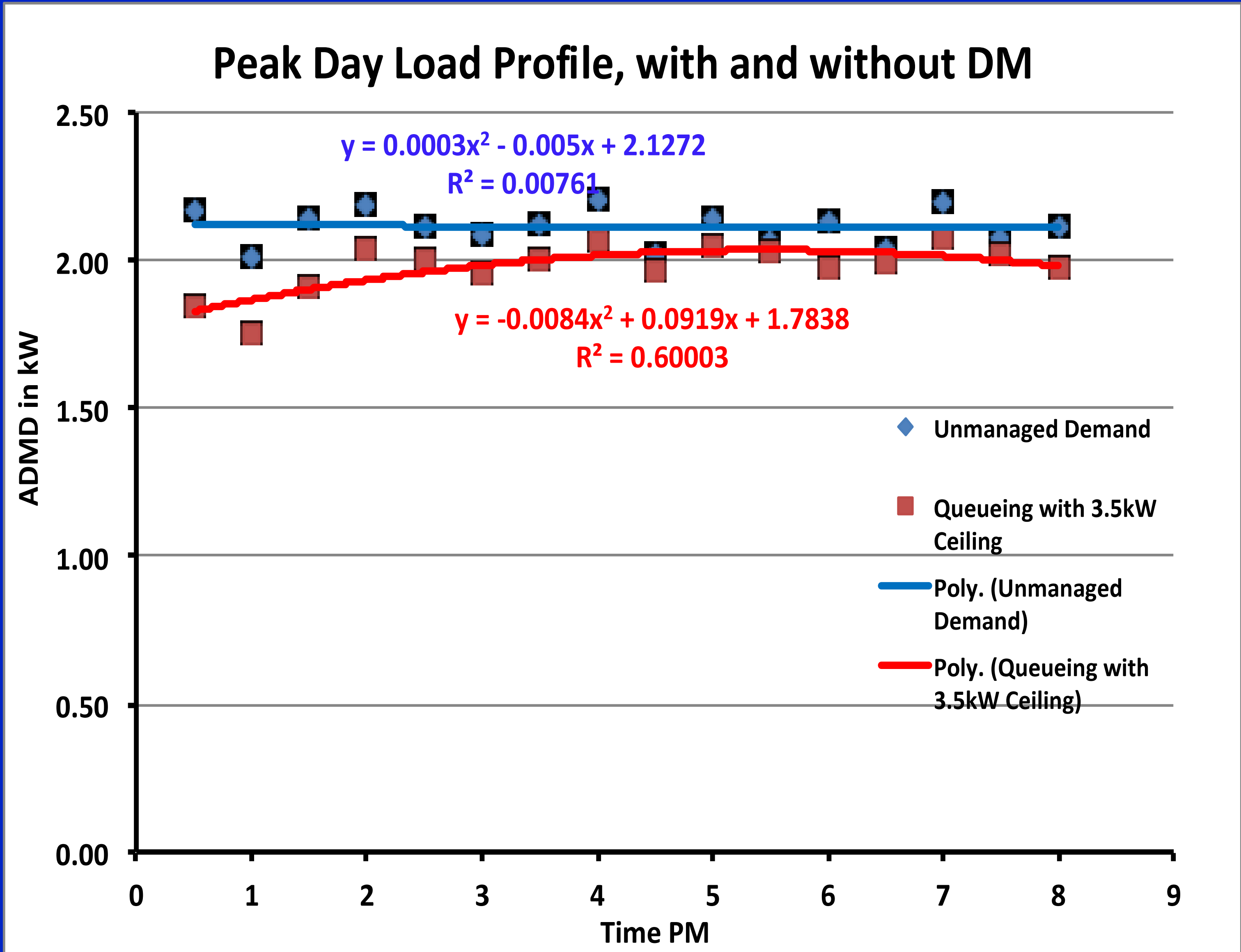
Expected (average across 8 hours) Contribution to collective demand reduced by 6 %

10% POE demand reduced by 9 %

6 % of load shifted beyond the peak period

But Managed Demand is not Uniform

% Connection point reduction is ACTUALLY 10 times collective reduction

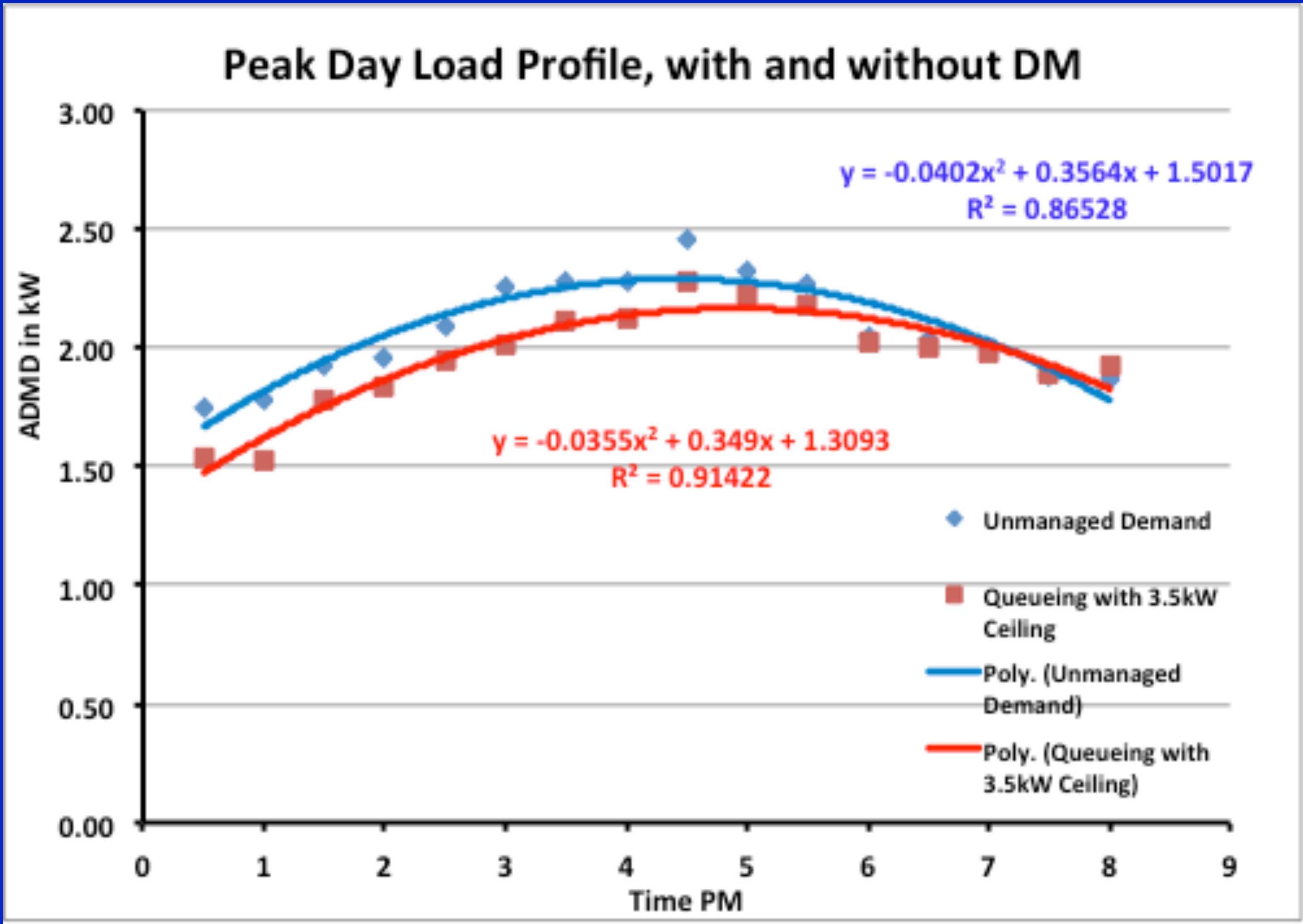


Whilst average demand across the 8 hours is reduced by 6%

Actual peak demand reduction is < 4%

Unmanaged Demand is not uniform, Either

Even assuming a 50% variation, % Connection point demand reduction is 8 times collective reduction



Average demand (across the 8 hours) is reduced by 5%.

And

Actual peak demand is reduced by 5%.

Alternative Demand Measurement

- If demand is measured as the average over the 8 hour period then collection point demand reduction becomes the same as the collective reduction (and matches % load deferred to beyond the peak period)
- This is essentially the same as a ToU Energy Tariff
- Queuing (under a demand ceiling) delivers only marginal benefit to the customer, but matched to the collective reduction
- Customer's motivation would logically shift to deferring (what can be deferred) beyond the peak period.
- If dish washing, clothes washing, drying and pool pumps are shifted demand and energy reduction becomes almost 50%.
- Without queuing connection point demand actually rises – to 4.2 kW, BUT Collective demand drops to 1.1 kW.

Summary

- Connection point Maximum Demand Tariffs, whether TOU or anytime, will incentivize a new set of perverse customer behaviors
- And result in a new set of intra class cross subsidies, which this time will see the less well off customers subsidizing larger better off customers who can afford both the appliances and the load management systems
- Measuring demand as the average over the periods when demand is likely to be maximum will ensure that connection point demand and contribution to collective demand align.
  - And will incentivize genuine load shifting.

Market Pricing & Regulated Monopolies

Shared Process - Product Pricing

- Examples from Competitive Industries
  - Butchers
    - Multiple products from a cow or sheep
  - Fractional Distillation & Cat Crackers
    - Multiple products from the distillation process
  - Airlines
    - Multiple flight times – each a different product
    - Service differentiation
- The cost of the shared production facility (the cow, the cat cracker or the aero plane), is allocated to the multiple outputs, according to their market value.

Shared Cost - Airlines

- Once committed to a fleet of planes, the airlines objective is to generate as much revenue, in excess of SRMC, as possible
- This can be achieved by pricing flights differently at different times according to market demand, so as to maximize the revenue excess.
  - Maximizing revenue is different to maximizing utilization.
- Floor price being SRMC

Application to Networks

Shared Capacity Costs

- **In the limit each 8760 half hourly interval could be priced so as to optimize either:**
  - revenue or volume, in that period
- **The floor price would be the SRMC, which for other than perhaps 1000 intervals would be zero.**
- Pragmatically this would be approximated by
  - A peak price for @ 300 or so hours and
  - A shoulder price for @ 700 or so hours
  - An off peak price for the remaining 7760 hours
- **TOU demand and energy converge**
- The critical pricing decision is whether to optimize
  - Revenue or volume
  - **An unregulated business would optimize revenue**
  - **A regulated business should optimize volume**

Application to Networks

Shared Connection Costs

- In URD developments the way in which the capital contribution (paid by the developer – actual cost) is recovered from the eventual lot purchasers, is determined by the market for residential lots – there is no rule that all should pay equally – premium lots are likely to pay a higher proportion.
- Ongoing maintenance and replacement costs are currently recovered through usage charges
- Better that they be recovered through fixed locational specific charges
- Why should not the basis of sharing those costs be market determined – but how does a monopoly do it?

The Ultimate Market Solution

Capacity, Connection & Sunk Costs

- **Retailers are currently competitive**
  - They buy energy in the wholesale market and charge retail customers according to their load profile, respond to competitive pressure and apply market risk premiums
  - They buy network access from DNSPs and pass through those charges = to the DNSPs end use customer tariffs.
    - I.e. DNSPs allocate the shared network costs to individual customers and retailers pass them on.
- **Consider the market alternative**
  - DNSPs charge Retailers in bulk for their collective retail customer demand and connection requirements and leave the
  - Retailer, by responding to market forces, to decide the allocation of shared costs to its individual retail customers.

Summary & Conclusion

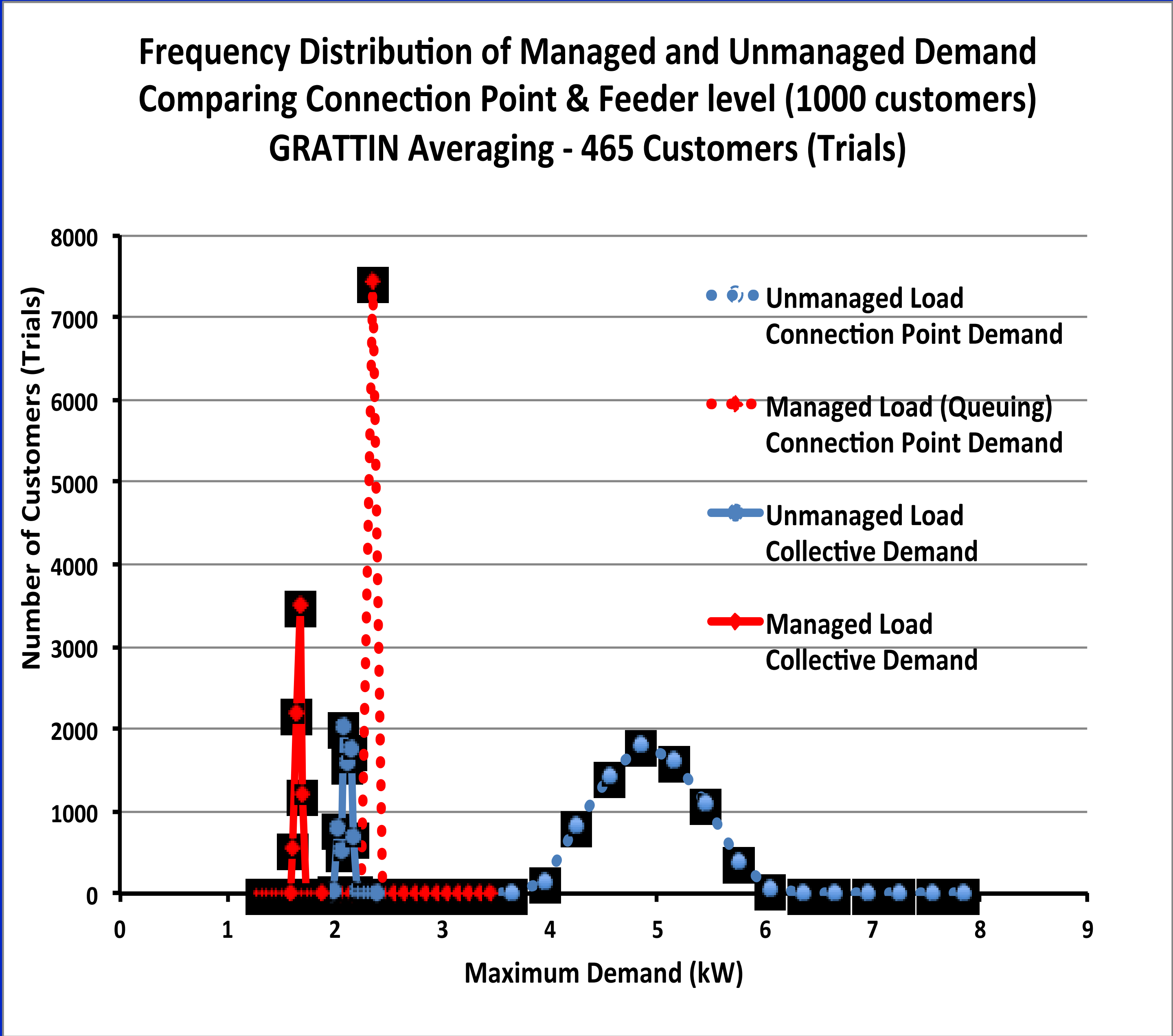
– The LRMC principal solves only a small part of the pricing challenge

– The current industry approach of introducing TOU Connection Point Demand Tariffs is fundamentally flawed and

– The use of "market value" is relevant to a regulated monopoly and may well provide the remainder of the solution.

Additional Slides

Non-Time Imperative Appliances, with a 2.4 kW Water Heater



Relative to 3.6kW case:

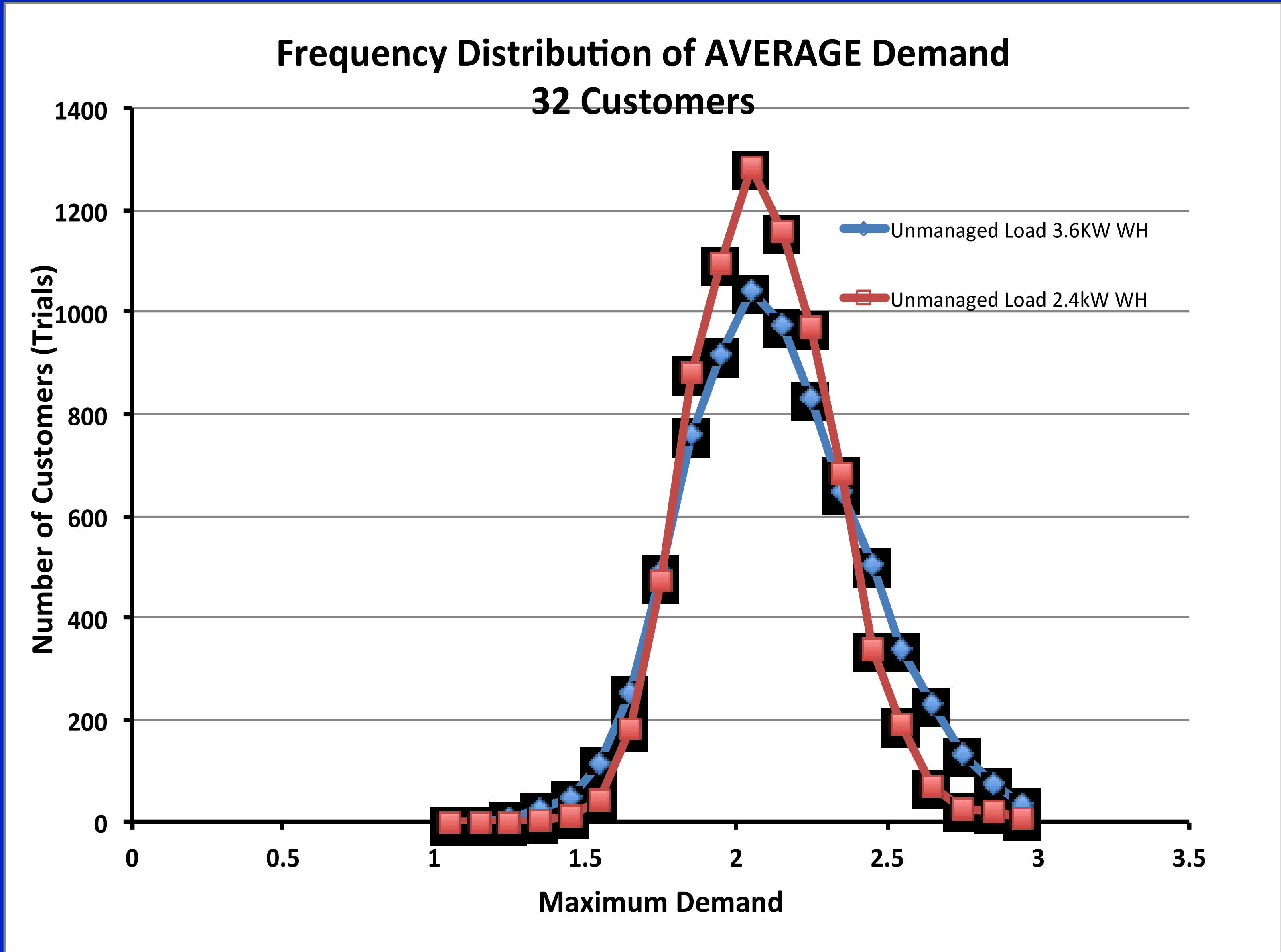
Chargeable demand reduced by 43 to 68 %

Expected Contribution to collective demand reduced by 21 %

10% PoE demand reduced by 25 %

16 % of load shifted beyond the peak period
Refrigeration 5%

Comparison of 3.6kW and 2.4kW Water Heater Modeling – Unmanaged Load



Ex ante Demand

If X_i are random variables, and if:

$$y = \sum_{\text{all } i} x_i$$

Then:

$$\mathcal{E}\,[\,y\,] = \sum_{\text{all } i} \mathcal{E}\,[\,x_i\,]$$

Where $\mathcal{E}$ is the expected value

Ex Ante Demand

If x_i are random variables, & if: & if x_i is homogeneous & independent

ii

$$y = \Sigma_{\text{all } i}\, x_i$$

Then: $\varepsilon\,[\,y\,] = \Sigma_{\text{all } i}\, \varepsilon\,[\,x_i\,] \quad = n.\varepsilon\,[\,x\,]$

And: $\sigma^2\,[\,y\,] = \Sigma_{\text{all } i}\, \sigma^2\,[\,x_i\,] \quad = n.\,\sigma^2\,[\,x\,]$

10% POE $[\,y\,] = \varepsilon\,[\,y\,] + k\,\sigma\,[\,y\,]$

per customer ADMD $= \varepsilon\,[\,x\,] + k\,.\,\sigma\,[\,x\,].\; n^{-0.5}$

Where ε is the expected value and σ = standard variation

Ex Ante Demand

If x_i are random variables, & if: & if x_i is homogeneous & independent

ii

$$y = \Sigma_{\text{all } i}\, x_i$$

Then: $\varepsilon\,[\,y\,] = \Sigma_{\text{all } i}\ \varepsilon\,[\,x_i\,]$ $= n.\varepsilon\,[\,x\,]$

And: $\sigma^2\,[\,y\,] = \Sigma_{\text{all } i}\ \sigma^2\,[\,x_i\,]$ $= n.\,\sigma^2\,[\,x\,]$

10% POE $[\,y\,] = \varepsilon\,[\,y\,] + k\,\sigma\,[\,y\,]$

per customer ADMD $= \varepsilon\,[\,x\,] + k\,.\,\sigma\,[\,x\,]\,/\,\sqrt{n}$

Where ε is the expected value and σ = standard variation