



low Energy COnsumption NETworks

ANNEX I OF THE DELIVERABLE D6.5

THE ESTIMATION MODEL APPLIED TO EVALUATE THE EXPECTED IMPACT OF ECONET TECHNOLOGIES

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Abstract

This document introduces some details on the estimation model and related parameter settings applied to evaluate the expected impact of ECONET technologies. In more detail, Section 1 introduces all the parameter values and the assumptions that were made along with their related detailed motivation. Section 2 introduces an outlook on the estimation procedure that was used for deriving the estimates.

1 Input Parameters Derivation

This section introduces a detailed list of all the assumptions, and related explanations, that have been made to determine the parameter settings in the final impact estimates of the ECONET technologies proposed in Deliverable 6.5.

The presence of such assumptions has proved necessary to correctly characterize the real potential gain of the proposed technologies, when applied to both real network deployment (rather than to the synthetic demonstration environment) and commercial products (rather than to academic/industrial research prototypes or evaluation boards).

The impact evaluation considered four scenarios, namely, “Business as Usual,” “Green Demonstration,” “Short-Term impact” and “Long-Term impact.”

These four scenarios are meant to map the experimental results obtained during the demonstration activities onto the device characterizations, densities and traffic levels that are typical in the different segments of operators’ networks.

The “Business as Usual” scenario, where no green optimizations are supposed to be applied, is only used as a term of comparison for evaluating the potential gains of the other scenarios, where the ECONET technologies are applied with increasing efficiency and level of deployment onto the network hardware. In this scenario, only few minor assumptions are made to reflect the differences between the demonstration prototypes and commercial devices deployed in operating networks.

The “Green Demonstration” scenario aims at representing the impact of the ECONET technologies in a similar way to the configuration deployed during the final demonstration of the project.

The raw experimental results obtained during the final demonstration have been complemented by additional energy gains coming from:

- Those green mechanisms that were available during the demonstration, but whose use was prevented by minor technical issues (e.g., the use of IEEE 802.3az in the HGs was prevented by the unavailability of suitable link-level counterparts);
- Those green mechanisms, whose impact was not directly included in the raw experimental results (e.g., the emulated traffic engineering/routing mechanisms);
- Those green mechanisms that were already demonstrated during the 2nd year review, and whose use was planned also in the final demonstration, but that could not be applied for logistic problems (e.g., “Zero Power Idle” at the access and home networks).

The “Short-term” scenario relies on the same assumptions as the “Green Demonstration” one, except for the hypothesis of the network being fully composed by green-enabled devices.

In its turn, the “Long-term” scenario starts from the assumptions of the previous one, and it applies some improvements expected from the evolutions of technologies and ECONET solutions in the next few years.

It is worth underlining that, in order to assure a fair comparison among the four selected scenarios, the assumptions are “incremental” according to green efficiency level of the scenario, in the sense that every assumption done in a certain scenario is considered to be kept in all the following ones (e.g., all the assumptions made in the BAU scenario are valid for all the other ones, the ones made for the “Green Demo” are valid also in the short- and long-term cases, etc.).

The following subsections describe all the assumptions made for each scenario, and the rationale of the improvement parameters applied in the “Long-term” case. These subsections include up to two tables each: the first one (if present) reports the parameter settings used in the scenario, the second one provides a detailed list of the assumptions made for deriving the impact estimate and the aforementioned parameter settings. Since this last table includes a number of assumptions inherited from the previous scenarios, the incremental ones (i.e., the ones not present in the previous scenarios) have been outlined.

For the sake of simplicity, Table I reports the definition of the parameters used to qualify and to quantify the expected improvements in energy efficiency of ECONET technologies. These parameters were already introduced and defined in the D6.5 report.

Table I. Parameter definition.

Parameter	Definition
σ	The shape parameter of the power consumption curve. In detail, the case $\sigma=1$ corresponds to the ideal case, where there is no overhead in entering and exiting from standby/idle states and the energy consumption increases linearly with respect to the traffic load λ .
N_{EAS}	Number of service rates provided by the device, one for each available Primitive Power Scaling Substate (P-PsS). These rates have been modelled as a discrete set uniformly distributed in the range $[0 - \mu_{max}]$, where μ_{max} represents the maximum device capacity.
ψ_{static}	Percentage of power reduction of ϕ_{static} considering the technological maturity of the energy-aware primitives; ϕ_{static} [W] is the part of the device power consumed even if the related device is idle (i.e., no packets received or transmitted).
ψ_{dyn}	Percentage of power reduction of ϕ_{dyn} considering the technological maturity of the energy-aware primitives; $\phi_{dyn}(\lambda)$ [W] represents the part of the energy consumption profile that can vary according to traffic load λ (ϕ_{dyn} corresponds to the energy profile when the device is active, excluded the ϕ_{static} bias).
ψ_{sleep}	Percentage of power reduction of ϕ_{sleep} considering the technological maturity of the energy-aware primitives; ϕ_{sleep} [W] is the power consumption when the device does not perform any operations (i.e., no packets received or transmitted). The parameters ϕ_{static} , ϕ_{dyn} , and ϕ_{sleep} represent the total power consumption of the device are used in the computation of the power consumption curve (Eq. (4) of the D6.5 report).
$\xi_{static-dyn}$	Percentage of energy consumption ϕ_{static} that is transformed to ϕ_{dyn} due to the absence of legacy hardware.
ξ	Percentage that represents the degree of network capacity <i>overprovisioning</i> . It indicates the maximum peak traffic load with respect to the network capacity. For example, if $\xi = 50\%$, then the maximum peak traffic load is 50% of the network capacity.

1.1 Business-As-Usual Scenario

Table II. Assumptions to determine the power consumption estimate in the Business as Usual scenario.

Clouds	Assumptions	Impact on Parameters
Transport	Switching matrix correctly dimensioned to the number of line-cards and ports	Average consumption per device decreased of 22 W.
Core	No assumptions	-
Metro	No assumptions	-
Datacenter	10% of ports are not connected	Average consumption of datacenter switches decreased of 2 W.
Access	Use of new Generation LQDE VDSL line-cards instead of legacy ones	DSLAM consumption decreased of 0.1 W per port
	Removal of the energy consumption of hardware components that are part of the evaluation board, but that are usually not included into final products	Consumption decreased of ~3.6 W in case of DSLAM, 4.2 W in case of access switch
Home	All the HG are set to the RED power state, WLAN enabled 24/7, DECT enabled 24/7, Analog phone hook enabled, DSL enabled 24/7, one Ethernet interface connected (non EEE) 24/7, average traffic load (when user is active) on Ethernet and WLAN = 50 Mbps, average user activity time = 25%. Note: this configuration corresponds to the “Maximum Power” one in Table XIV of D6.5, but with slightly different traffic levels.	Average consumption per device = 13.6 W
	Removal of the energy consumption of hardware components that are part of the evaluation board, but that are usually not included into final products	Consumption decreased of ~0.5 W Average consumption per device = 13.1 W

1.2 Green Demo Scenario

Table III. Parameter settings for the “green demo” impact estimate in all the cloud networks.

Parameter	Transport	Core	Metro	Datacenter	Access	Home
ψ_{static}	0%	0%	0%	0%	0%	0%
ψ_{dyn}	0%	0%	0%	0%	0%	0%
ψ_{sleep}	0%	0%	0%	0%	0%	0%
$\xi_{static-dyn}$	0%	0%	0%	0%	0%	0%
ξ	50%	50%	50%	50%	50%	30%

Table IV. Assumptions to determine the parameter settings in the “green demo”.

Clouds	Assumptions	Impact on Parameters
Transport	Switching matrix correctly dimensioned to the number of line-cards and ports	Average consumption per device decreased of 22 W.
	Links and devices entering standby mode during night time thanks to the green Traffic Engineering mechanisms	1 device fully sleeping every 8, 50% of sleeping links
Core	20% of links entering standby mode thanks to green routing strategies	Average consumption decreased of 10 W
Metro	No assumptions	-
Datacenter	10% of ports are not connected	Average consumption of datacenter switches decreased of 2 W.
Access	Use of new Generation LQDE VDSL line-cards instead of legacy ones	DSLAM consumption decreased of 0.1 W per port
	Removal of the energy consumption of hardware components that are part of the evaluation board, but that are usually not included into final products	Consumption decreased of ~3.6 W in case of DSLAM, 4.2 W in case of access switch
	DSL in standby mode during user inactivity time (by means of the “Zero Power Idle” mechanisms introduced in Sect. 9.3.2 of D6.2 ¹)	Energy profile decreased of ~0.67 W per port during user inactivity
Home	Green power mode set, DECT enabled 24/7, Analog phone hook enabled 24/7, same traffic and user conditions as in the BAU case. WLAN enabled 24/7 during the day (i.e., 66% of the time)	Energy profile is set to the one measured in the demo experiments
	Removal of the energy consumption of hardware components that are part of the evaluation board, but that are usually not included into final products	Energy profile decreased of ~0.5 W bias
	DSL in standby mode during user inactivity time (by means of the “Zero Power Idle” mechanisms introduced in Sect. 9.3.2 of D6.2 ¹)	Energy profile decreased of ~0.67 W during user inactivity
	The 2 Ethernet ports work with IEEE 802.3az	Energy profile decreased of ~1.15 W during user inactivity time and of ~0.4 W during user activity time

¹ The ECONET Consortium decided to include the gains of those green mechanisms that were almost ready to be included in the final demonstrator, but that were excluded for minor technical/integration issues (some of these mechanisms were already part of the 2nd year demonstrations).

1.3 Short-Term Scenario

Table V. Parameter settings for the short-term impact estimate in all the cloud networks.

Parameter	Transport	Core	Metro	Datacenter	Access	Home
σ	0.90	0.75	0.75	0.75	0.90	0.90
N_{EAS}	2	10	12	2	3	3
ψ_{static}	0%	0%	0%	0%	0%	0%
ψ_{dyn}	0%	0%	0%	0%	0%	0%
ψ_{sleep}	0%	0%	0%	0%	0%	0%
$\xi_{static-dyn}$	40%	35%	40%	30%	0%	25%
ξ	50%	50%	50%	50%	50%	30%

Table VI. Assumptions to determine the parameter settings in the short-term scenario.

Clouds	Assumptions	Impact on Parameters
Transport	Switching matrix correctly dimensioned to the number of line-cards and ports	Average consumption per device decreased of 22 W.
	Links and devices entering standby mode during night time thanks to the green Traffic Engineering mechanisms	1 device fully sleeping every 8, 50% of sleeping links
	Legacy hardware share in the demonstrator	$\xi_{static-dyn} = 40\%$
Core	20% of links entering standby mode thanks to green routing strategies	Average consumption decreased of 10 W
	Legacy hardware share in the demonstrator	$\xi_{static-dyn} = 35\%$
Metro	Legacy hardware share in the demonstrator	$\xi_{static-dyn} = 40\%$
Datacenter	10% of ports are not connected	Average consumption of datacenter switches decreased of 2 W.
	Legacy hardware share in the demonstrator	$\xi_{static-dyn} = 30\%$
Access	Use of new Generation LQDE VDSL line-cards instead of legacy ones	DSLAM consumption decreased of 0.1 W per port
	Removal of the energy consumption of hardware components that are part of the evaluation board, but that are usually not included into final products	Consumption decreased of ~3.6 W in case of DSLAM, 4.2 W in case of access switch
	DSL in standby mode during user inactivity time (by means of the “Zero Power Idle” mechanisms introduced in Sect. 9.3.2 of D6.2)	Energy profile decreased of ~0.67 W per port during user inactivity
	Green power mode set, DECT enabled 24/7, Analog phone hook enabled 24/7, same traffic and user conditions as in the BAU case. WLAN enabled 24/7 during the day (i.e., 66% of the time)	Energy profile is set to the one measured in the demo experiments
Home	Removal of the energy consumption of hardware components that are part of the evaluation board, but that are usually not included into final products	Energy profile decreased of ~0.5 W bias
	DSL in standby mode during user inactivity time (by means of the “Zero Power Idle” mechanisms introduced in Sect. 9.3.2 of D6.2)	Energy profile decreased of ~0.67 W during user inactivity
	The 2 Ethernet ports work with IEEE 802.3az	Energy profile decreased of ~1.15 W during user inactivity time and of ~0.4 W during user activity time
	Legacy hardware share in the demonstrator	$\xi_{static-dyn} = 25\%$

1.4 Long-Term Scenario

Table VII. Parameter settings for the long-term impact estimate in all the cloud networks.

Parameter	Transport	Core	Metro	Datacenter	Access	Home
σ	0.90	0.75	0.75	0.75	0.75	0.80
N_{EAS}	5	10	12	4	5	5
ψ_{static}	30%	20%	47%	30%	55%	45%
ψ_{dyn}	25%	5%	33%	10%	23%	25%
ψ_{sleep}	30%	5%	45%	7%	18%	7%
$\xi_{static-dyn}$	50%	45%	50%	34%	15%	50%
ξ	50%	50%	50%	50%	50%	30%

Table VIII. Assumptions to determine the parameter settings in the long-term scenario.

Clouds	Assumptions	Impact on Parameters
Transport	Switching matrix correctly dimensioned to the number of line-cards and ports	Average consumption per device decreased of 22 W.
	Links and devices entering standby mode during night time thanks to the green Traffic Engineering mechanisms	1 device fully sleeping every 8, 50% of sleeping links
	Legacy hardware share in the demonstrator	$\xi_{static-dyn} = 40\%$
	Tuning of standby and power scaling hardware elements	$\psi_{dyn} \pm 5\%$
	DC/DC converters with higher efficiency	$\xi_{static-dyn} \pm 10\%$
	Voltage regulation in the presence of temperature-controlled ambient (Sect. 5.1.1.2.3, pag. 57, D3.3)	$\psi_{static} \pm 10\%$
	Use of next-generation FPGA technologies with enhanced voltage and clock gating performance	$\psi_{sleep} \pm 10\%$ $\psi_{static} \pm 20\%$ $\psi_{dyn} \pm 20\%$
	Integration with optical bypass mechanisms to enable more ports/devices to enter standby modes	$\psi_{sleep} \pm 20\%$
	Power scaling and standby mechanisms enabled at the switching matrix	$\psi_{dyn} \pm 10\%$
Core	20% of links entering standby mode thanks to green routing strategies	Average consumption decreased of 10 W
	Legacy hardware share in the demonstrator	$\xi_{static-dyn} = 35\%$
	Power Scaling mechanisms activated in DROP Interconnection Elements	$\psi_{dyn} \pm 5\%$ $\psi_{sleep} \pm 5\%$
	Use of next-generation SoC technologies with enhanced voltage and clock gating performance, and with the capability of shutting down unused components (i.e., accelerators or core pipelines)	$\xi_{static-dyn} \pm 10\%$ $\psi_{static} \pm 20\%$
Metro	Legacy hardware share in the demonstrator	$\xi_{static-dyn} = 40\%$
	Use of next-generation network processors with built-in power scaling and standby capabilities	$\psi_{static} \pm 25\%$ $\psi_{sleep} \pm 20\%$ $\psi_{dyn} \pm 33\%$
	DC/DC converters with higher efficiency	$\xi_{static-dyn} \pm 10\%$
	Integration with optical bypass mechanisms to enable more ports/devices to enter standby modes	$\psi_{sleep} \pm 25\%$
	Green temperature and cooling adaptation mechanisms	$\psi_{static} \pm 22\%$

Datacenter	10% of ports are not connected	Average consumption of datacenter switches decreased of 2 W.
	Legacy hardware share in the demonstrator	$\xi_{static-dyn} = 30\%$
	DC/DC converters with higher efficiency	$\xi_{static-dyn} \pm 4\%$
	Use of network-wide traffic engineering mechanisms to put switch ports into standby modes and to better exploit power scaling modes	$\psi_{static} \pm 15\%$ $\psi_{sleep} \pm 7\%$
	Adoption of new generation ASICs and design of more efficient clock and voltage gating mechanisms	$\psi_{static} \pm 15\%$ $\psi_{dyn} \pm 10\%$
Access	Use of new Generation LQDE VDSL line-cards instead of legacy ones	DSLAM consumption decreased of 0.1 W per port
	Removal of the energy consumption of hardware components that are part of the evaluation board, but that are usually not included into final products	Consumption decreased of ~3.6 W in case of DSLAM, 4.2 W in case of access switch
	DSL in standby mode during user inactivity time (by means of the “Zero Power Idle” mechanisms introduced in Sect. 9.3.2 of D6.2)	Energy profile decreased of ~0.67 W per port during user inactivity
	DC/DC converters with higher efficiency	$\xi_{static-dyn} \pm 10\%$
	Use of next-generation FPGA technologies with enhanced voltage and clock gating performance	$\psi_{sleep} \pm 8\%$ $\psi_{static} \pm 25\%$ $\psi_{dyn} \pm 8\%$
	Extension to vectored VDSL in order to support dynamic adaptive link rates	$\psi_{dyn} \pm 15\%$ $\psi_{sleep} \pm 10\%$
	Splitting DSLAM functionalities (sect. 5.2.1.1.3, D3.3)	$\psi_{static} \pm 30\%$
Home	Tuning of VDSL line-drivers and of vectoring engine	$\xi_{static-dyn} \pm 5\%$
	Green power mode set, DECT enabled 24/7, Analog phone hook enabled 24/7, same traffic and user conditions as in the BAU case. WLAN enabled 24/7 during the day (i.e., 66% of the time)	Energy profile is set to the one measured in the demo experiments
	Removal of the energy consumption of hardware components that are part of the evaluation board, but that are usually not included into final products	Energy profile decreased of bias of ~0.5 W
	DSL in standby mode during user inactivity time (by means of the “Zero Power Idle” mechanisms introduced in Sect. 9.3.2 of D6.2)	Energy profile decreased of ~0.67 W during user inactivity
	The 2 Ethernet ports work with IEEE 802.3az	Energy profile decreased of ~1.15 W during user inactivity time and of ~0.4 W during user activity time
	Legacy hardware share in the demonstrator	$\xi_{static-dyn} = 25\%$
	DC/DC converters with higher efficiency	$\xi_{static-dyn} \pm 10\%$
	Sleeping VDSL connection for longer times thanks to the green proxy	$\psi_{sleep} \pm 7\%$
	Use of next-generation SoC technologies with enhanced voltage and clock gating performance, and with the capability of shutting down unused components (i.e., accelerators or core pipelines)	$\xi_{static-dyn} \pm 15\%$ $\psi_{static} \pm 25\%$
	Redesign of clock and voltage domains to better support selective standby and power scaling of internal hardware elements	$\xi_{static-dyn} \pm 15\%$ $\psi_{static} \pm 20\%$
	Green load balancing at accelerators with parallel pipelines	$\psi_{dyn} \pm 15\%$
	Revision and better support to power scaling modes of MIPS cores	$\psi_{dyn} \pm 10\%$

2 Overview of the Impact Estimation Procedure

Figure 1 reports the main calculation blocks that are used to estimate the energy consumption in the 4 scenarios considered in D6.5. This flow diagram is reported in order to make the understanding of the estimation procedure easier and to pinpoint the roles of the parameters and of the assumptions described in the previous sections. For all the scenarios, the calculation steps reported in the flow diagram are independently made for each demonstration cloud.

The main input parameters of the estimation procedures consist of the traffic load and energy consumption values measured during the demonstration tests and the parameters defined in Table I. The traffic load and energy consumption values are passed to the estimation procedure as vectors (i.e., one value for each time slot reproduced in the demonstration test), and are initially elaborated in a separate fashion. Traffic loads are expressed as percentage of utilized bandwidth of the available capacity. Energy consumption values are averaged over all the devices composing the selected cloud, so that it is possible to pass from the energy consumption of the entire cloud to the average one of a single device belonging to it. Moreover, the bias on the energy consumption values due to the assumptions in Table II (kept valid also in the other scenarios) is removed from all the values in the energy consumption vector.

The so elaborated traffic and the energy consumption vectors are used to calculate the so-called “energy-profile function,” which is aimed at representing how energy consumption varies according the traffic utilization in a full range between 0% and 100% (and not only for the traffic levels measured during the demonstration tests). This function is calculated in all the scenarios except the Business as Usual one, where the results obtained on the two vectors are directly passed to the final blocks.

In order to obtain this function the following steps are followed. The aforementioned vectors are merged in order to compose a $2 \times N_{slot}$ matrix, where each row contains the traffic utilization and the energy consumption related to the same time-of-day slot. The pairs are re-ordered according to increasing traffic utilization, and a 15th order polynomial is fitted against these ordered values by using the least squares method.

Since the fitting is a good approximation only inside the traffic utilization range used during the demonstration (i.e., the traffic range where fitting samples reside), it was decided to fix the value of the energy-profile for traffic utilization values outside the fitting range. When the traffic utilization is lower than the fitting range, the output of the function is set to the lower bound of the energy consumption that was measured for that device. On the contrary, for utilization values exceeding the range, the function output is set to the related upper bound of the energy consumption.

At the same time, the traffic utilization vector is scaled in order to assure that the maximum link utilization in the cloud is equal to the ξ parameter.

The energy-profile function and the scaled traffic profile are used to calculate the average energy consumption of the device.

Only in case of short- and long- term impact scenarios the “Energy Profile Model” introduced in the D6.5 report (sect. 4.1) is applied for calculating additional energy gains coming from the assumptions in Table VI and Table VIII.

Finally, the energy consumption of the device is multiplied by the expected “cloud” density of the reference network (i.e., the number of devices that are expected to be deployed into that cloud).

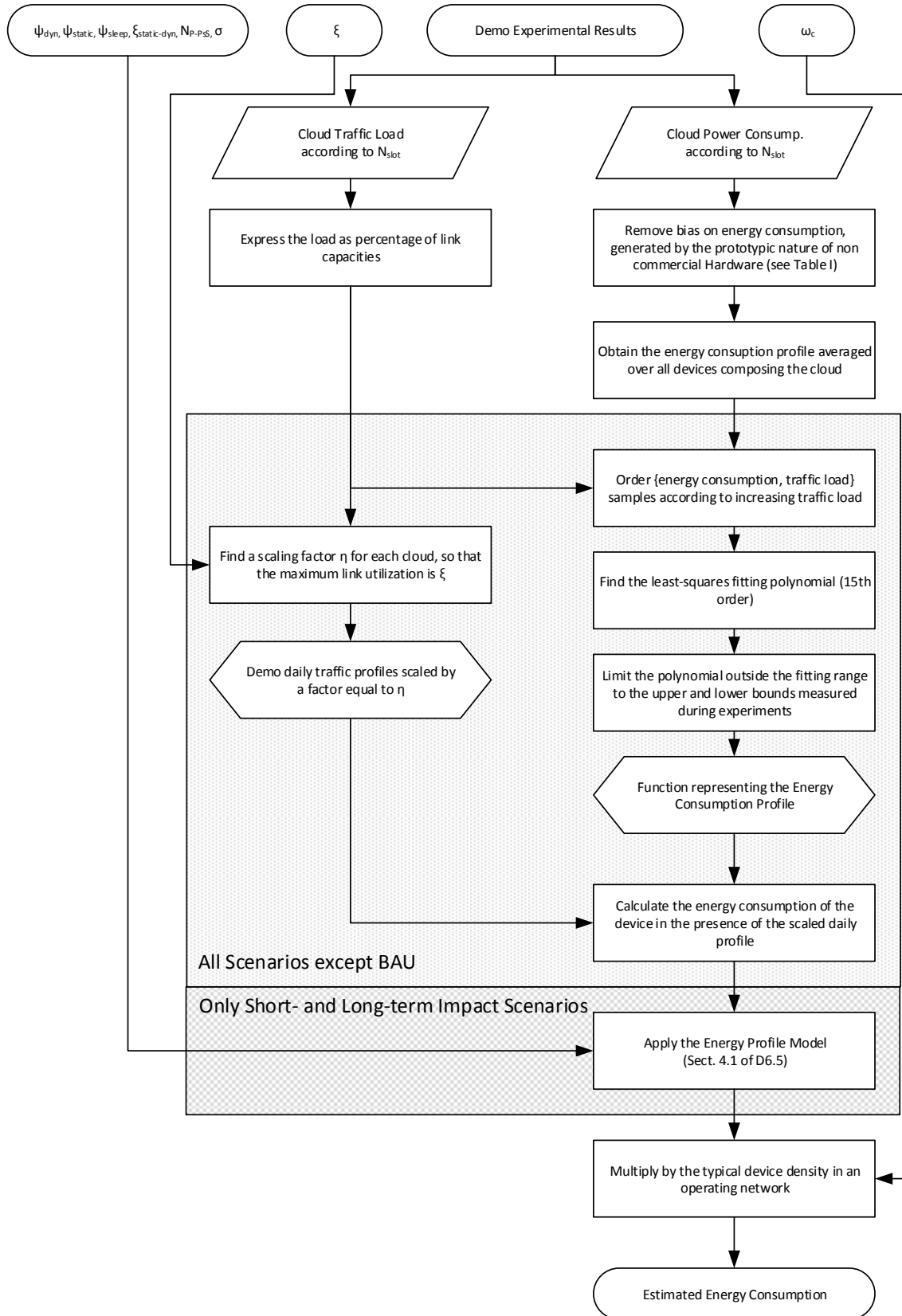


Figure 1. Flow diagram of the main operations that are done for estimate the energy consumption in the 4 considered scenarios.