User Instructions and Manual for the SDC System Simulation Spreadsheet

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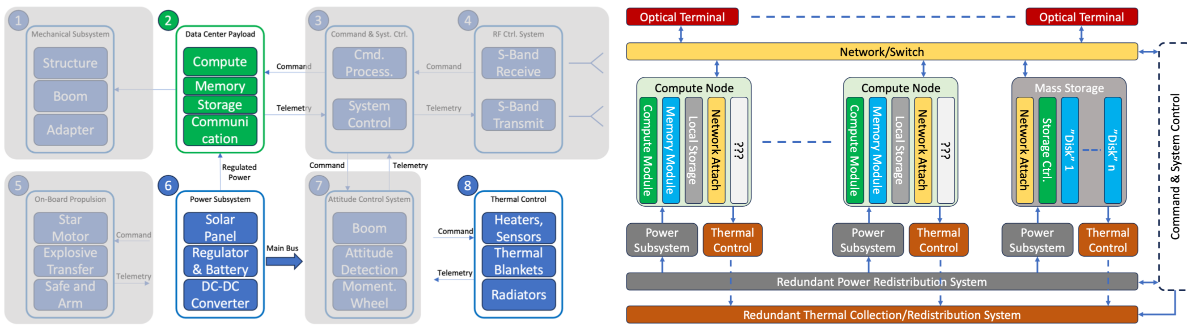
Introduction

The SDC (Space Data Center) System Simulator is an Excel, visual basic (VBA) enhanced system performance assessment tool for edge-computing scenarios in space. It has an underlying model of different system components of a satellite with a compute- and communication payload. The System-components which are modeled with various degrees of details are shown in below figure left (2), (6) and (8). Other system components (greyed-out) are accounted for on an aggregated level. The compute payload is then further refined into compute- and storage nodes, including thermal and power infrastructure (figure below on the right).



The results are computed by combining values of many different/relevant technology roadmaps, together with user-requirements into a few specific figures of merit (FOMs), such as **Cost per Compute**, **Power per Compute** or **Cost per Power**. Additional values are also provided, either numerically or a selection thereof can be plotted against each other.

It is imperative to **Enable Macros** when opening the spreadsheet for it to work properly!

To improve robustness, values are not referred to with their cell-coordinates, but rather by definition of Named Variables (see ***-> Formulas -> Name Manager*** for the full list).

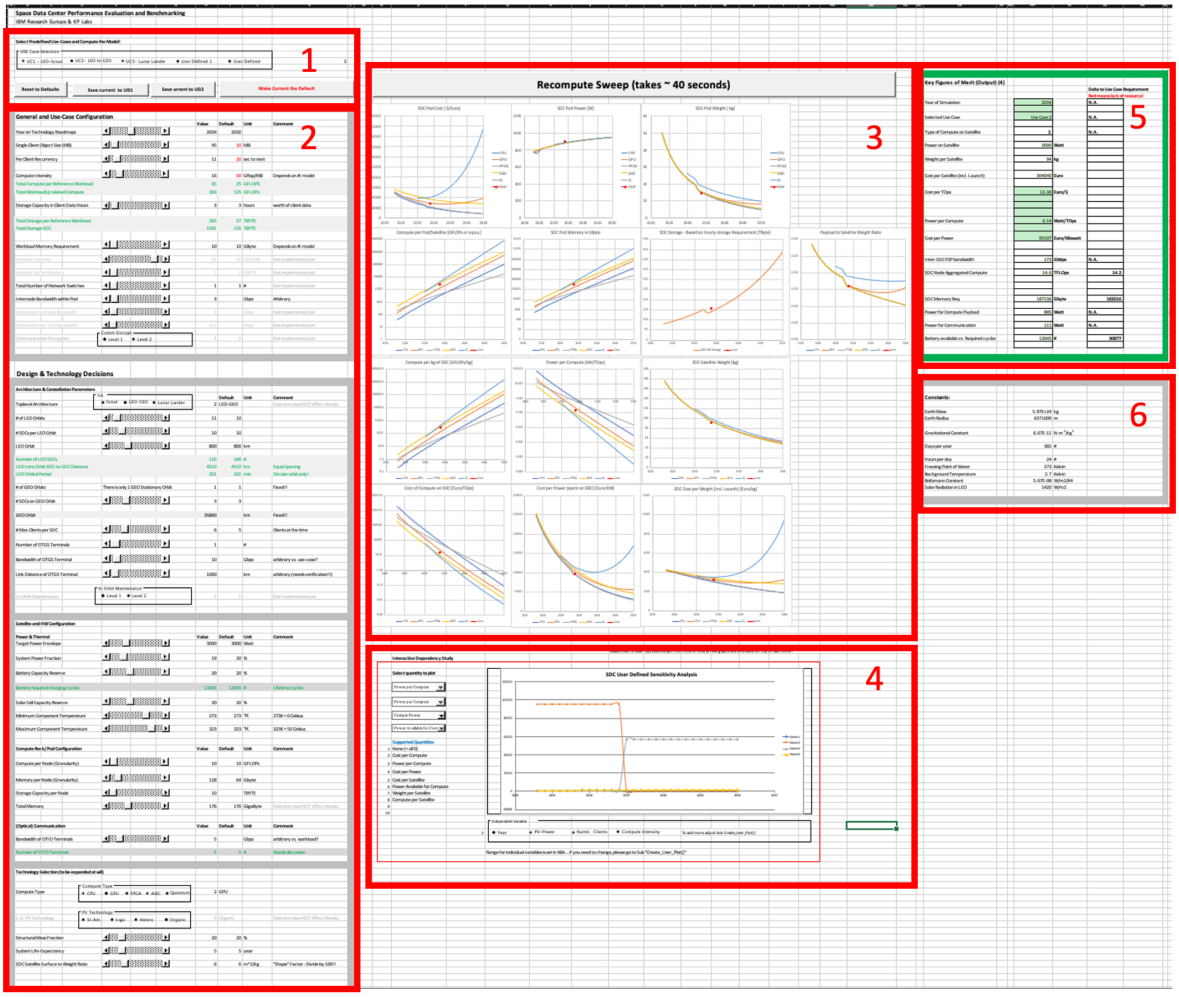
By using the "Name Manager" and named ranges extensively, the entire spreadsheet could be made relatively robust against shifting cells in sheets. However, it is highly discouraged to change the names of the individual sheets, as it was necessary to hard code their access with their respective names all over in the VBA code.

Please Note: For the spreadsheet to work in its current way, many technology performance metrices had to be simplified and were mapped to liner or exponential growth curves, sometimes simply by creating fractions of current performance, power and weight indications. **The relevance and value of the results of this "simulator" has thus to be seen in the trends and comparison between different quantities/trends it provides, and NOT in absolute values!**

User Interface (UI)

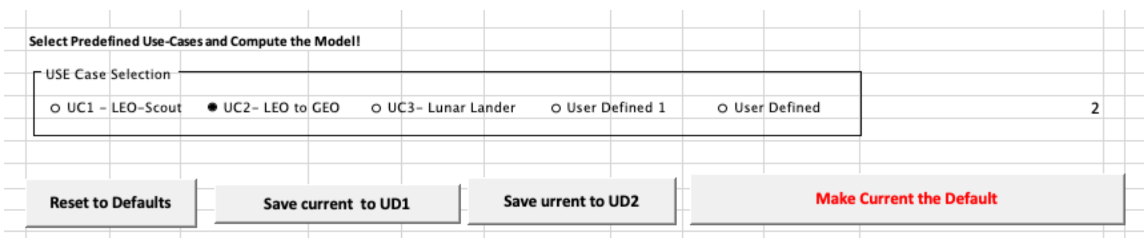
The Simulation Spreadsheet consists of various tabs. However, the main sheet to interact with the tool, is the ***SDC Summary*** sheet, as shown below. For best experience, a rather large screen is recommended.

The main interface consists of 5 user-relevant sections (1-5).



UI Section 1

This section allows to select and preload existing and user-defined scenarios. The values for the different scenarios are fetched from or saved to a large table in on the sheet ***Use-Case Definitions***. To adjust a pre-set use-case, values on the latter table must be changed, while interactive, user-defined use-cases can be saved with a button-click to one of the two User-Defined configurations.



UI Section 2

This section allows to manually adjust individual values and to experiment with the results. This is possible either by using the sliders (despite that they are configured for manual sliding and page "jumps", mostly single up/down increments work smoothly, since every change triggers a recompute of the entire model and update of the charts in **Section 3**) or by entering values directly into the "Value" column, which will be reflected in the slider position as well.

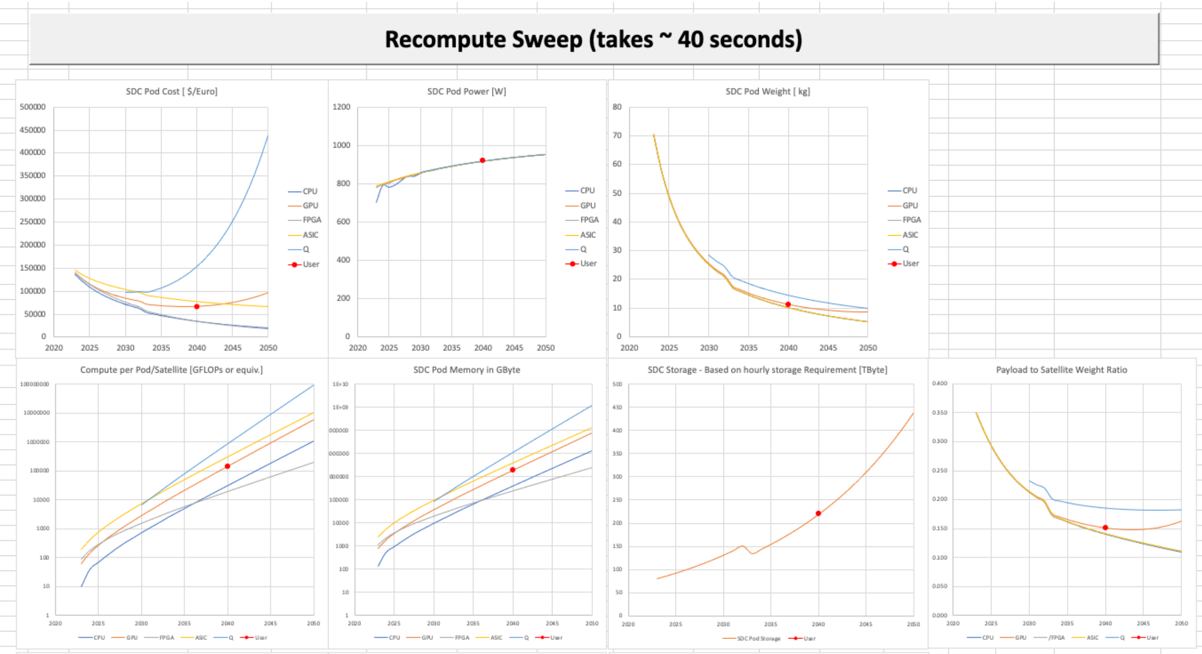
Below, a screenshot of one of the many subsections of **Section 2** is shown. Additionally, to numeric values, also radio-buttons are used to facilitate selecting e.g. architectural or technological choices. Changes made in this section will immediately be reflected by the *red dot* in the figures in **Section 3**.

If numbers are displayed in *green*, they are computed in the cell, based on other values and should not be touched/changed (see also the coloring convention).

Architecture & Constellation Parameters			Default	Unit	Comment
Toplevel Architecture	TLA: ○ Scout ● LEO-GEO ○ Lunar Lander	LEO-GEO	LEO-GEO		Selection does NOT Affect Results
# of LEO Orbits		11	10		
# SDCs per LEO Orbit		10	10		
LEO Orbit		800	800	km	
Number of LEO SDCs		110	100	#	
LEO Intra Orbit SDC-to-SDC Distance		4510	4510	km	Equal Spacing
LEO Orbital Period		201	201	min	Circular orbit only!
# of GEO Orbits	There is only 1 GEO Stationary Orbit	0	1		Fixed!!

UI Section 3

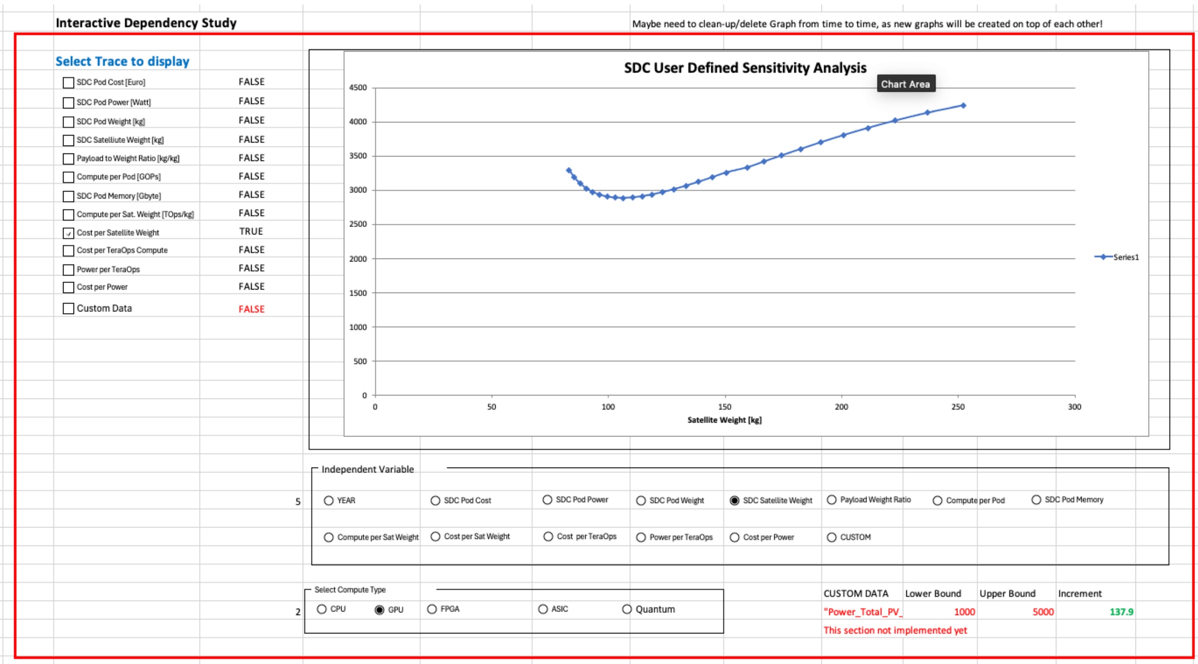
This is the main reporting section, where various performance relevant quantities are plotted over time.



To refresh the plots, hit the **“Recompute Sweep”** button. This will trigger a recompute of the entire underlying data, for every year and for every type of compute (CPU, GPU, … , Quantum), with the current requirements set in **Section 2**. The data for the plots is written to the **temp_data** sheet. During the recompute process, you will be able to see the **Technology_Roadmap** sheet, where you can observe continuous changes in the value-column. On the very top the year will count up to 2050, which gives you an indication how close to completion the process is. After completion, you will be automatically redirected to the **SDC Summary** sheet again, for inspecting the new graphs and continue your evaluation of other requirements.

UI Section 4

In this section, you can choose to plot all computed FOMs against each other or against time. Every time you select a different x-axis, the graph will be recreated, with all checked data from the left. As the figure will be regenerated on top of the existing chart, you may want to clean-up, i.e. delete underlying charts from time to time.
All data is based on the results from applying the “Recompute Button” and is NOT affected by temporary changes of the requirements. If such need to be accounted for, please **press “Recompute Sweep”** before.
Please note, that all data here is fetched from the ***temp_data*** sheet, thus is not fully independent, but has rather always time as an implicit parameter.
To be able to select any of the requirement variables from **Section 2** as a sweep parameter, is not implemented yet, but may yield interesting dependencies in the future.
Curves in this section are always only given for one of the compute types available, which must be selected (a change thereof also triggers a regeneration of the chart).



UI Section 5

This section provides numerical values for the key figures of merit (FOMs) as defined in the statement of work, including some references to the "conditions" they were evaluated.

The right column evaluates "reserves" with respect to specific use-case requirements, where applicable.

Please note: The key figures of merit displayed here, are not the result of an optimization scheme, but rather derived from the given power-envelope, i.e. the compute available is the maximum compute performance possible within the available power of the solar panels and the given compute technology.

Key Figures of Merit			
			Delta to Use Case Requirement **Red means lack of resource!**
Year of Simulation	2036		N.A.
Selected Use Case	Use Case 2		N.A.
Type of Compute on Satellite	2		N.A.
Power on Satellite	5000	Watt	
Weight per Satellite	141	kg	
Cost per Satellite (incl. Launch)	499007	Euro	
Cost per TOps	2.20	Euro/$	
Power per Compute	0.02	Watt/TOps	
Cost per Power	99801	Euro/Kilowatt	
Inter-SDC P2P bandwidth	173	Gbitps	N.A.
SDC Node Aggregated Compute	227.1	TFLOps	226.7
SDC Memory Req.	2906880	Gbyte	2901760
Power for Compute Payload	1496	Watt	N.A.
Power for Communication	97	Watt	N.A.
Battery available vs. Required cycles	13045	#	34030

UI Section 6

This section is reserved for physical and other constants required during model evaluation.

Coloring Convention

The coloring convention for values in the spreadsheet is generally as follows:

- Black: Values are defined/entered there
- Blue: Values are defined somewhere else and only shown for reference
- Green: Values are computed in the cell (should not be changed)
- Red/Yellow: Issue/uncertainty with/of the value or not implemented yet. Special attention should be given to these values
- Grey: Values/quantities for future use/implementation

Color of frames/outlines:

- No consistent scheme applied here.

Simulation Data Source

The simulation model relies on 2 principal sources of data. 1) the Use-Case Definitions (sheet), which are also reflected and modified on the UI value column and 2) the Technology_Roadmaps (sheet) of a vast numbers of quantities, of which always the values in the “Value” column will be used to evaluate the current model.

Use-Case Definitions Sheet

On the **Use-Case Definitions** Sheet, different predefined and user-defined requirements, specific to a given use-case can be entered.
To simplify the underlying VBA code, all data is on the very same rows as the user-adjustable requirements from the UI on the **SDC Summary** sheet. Using the radio-buttons on the UI sheet, simply copies the relevant column from Use-Case Definitions to the “value” column of the SDC Summary sheet, which is used by the model(s) to compute the figures of merit and the “red point” on the graphs, or the graphs themselves during the sweeps.
If the user has a set of requirements between which he/she wants to switch, 2 user-defined columns are available to store them. By means of button clicks on the UI sheet (Section 1), values can be stored to or by selecting the radio buttons, retrieved from these sections. The same applies to the default column.

This space left blank on purpose!
This way the VBA script can copy directly corresponding row-values without translation!
Please make sure rows in this tab correspond to rows in "SDC Summary" !

General and Use-Case Configuration	Use-Case 1	Use-Case 2	Use-Case 3	User Def. 1	User Def. 2	Default Values	Units	Comments
Year on Technology Roadmaps	2030	2035	2040	2035	2050	2030		
Single Client Object Size (MB)	45	45	100	45	200	10	MB	
Per Client Recurrency	20	11	11	11	11	20	sec to next	
Compute Intensity	16	16	16	16	16	50	Gflop/MB	Depends on AI model
Storage Capacity in Client Data Hours	1	3	3	3	3	3	hours	worth of client data
Workload Memory Requirement	10	10	10	10	10	10	GByte	Depends on AI model
Network Intensity	91	91	91	91	91	30	Gbit/MB	Not implemented yet
Network Buffer Memory	1	1	1	1	1	0	GBYTE	Not implemented yet
Total Number of Network Switches	1	1	1	1	1	1	#	Not implemented yet
Internode Bandwidth within Pod	1	3	3	5	1	1	Gbps	Arbitrary
Estimated Internode Bandwidth	3	3	3	3	3	3	Gbps	Not implemented yet
Estimated Inter-SDC Bandwidth	0.5	0.5	0.5	0.5	0.5	0.5	Gbps	Not implemented yet
Communication Encryption	1	1	1	2	1	1		Not implemented yet
Design & Technology Decisions								
Architecture & Constellation Parameters								

Technology Roadmap Sheet

This sheet constitutes the major source of data that is used in computing the models. It consists of over 50 individual "roadmaps" of technologies involved or required in the building of a space data center satellite constellation. Most of them are assumed to be of exponential nature with the time in years where performance doubling is expected in column "F". Current performance metric (as of 2023) is in the "Default" column and growth rate are often educated guesses from literature studies, but absolutely open to discussion and improvement. The latter or on Column "F".

For some values a linear growth is assumed, which is easily visible by the yellow font of the growth rate.

For practical reasons, performance roadmaps for the different compute types (CPU, GPU, FPGA, ASIC and Quantum), is separated from this list. Values are copied "on-demand" into the upper section (row 4-6) depending on the selection of the compute-type, either by user or VBA scripts.

Also in this section, extensive use of named ranges has been made, by naming the first entries per row and using their row-index in the software code. This will allow to add more rows in the future without the need to rewrite and correct the VBA code.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	**Reference Technology Values for Sim - Values used in Scenario!**						**YEAR**	2023	2024	2025	2026	2027	2028	2029
2		**Value**	**Default**	**Unit**		**Performance Doubling Every XY Years**								
3	**YEAR**	2036	2023			red = exponential, yellow = linear								
4	***Power per Compute:***	0.006	0.1	W/GFLOPS	Assume Start in 2030	1.5	Quantum							
5	***Cost per Compute:***	0.006	0.10	$/GFLOPS		1.5	Quantum							
6	***Weight per Compute:***	0.031	0.50	kg/TOps		1.5	Quantum							
7														
8														
9	Cost per Memory	0.04	4.00	$/GBYTE		2.0		4.00	2.83	2.00	1.41	1.00	0.71	0.50
10	Memory per Module	80.63	4.00	GBYTE		3.0		4.00	5.04	6.35	8.00	10.08	12.70	16.00
11														
12	**Mass (Storage_)**													
13	Terabyte per module	285.41	30.00	TBYTE		4.0		30.00	35.68	42.43	50.45	60.00	71.35	84.85
14	Cost per Capacity	0.09	8.00	$/TBYTE		2.0		8.00	5.66	4.00	2.83	2.00	1.41	1.00
15	Weight per Capacity	0.11	10.00	g/TBYTE		2.0		10.00	7.07	5.00	3.54	2.50	1.77	1.25
16	Power per Capacity	0.05	1.00	W/TBYTE		3.0		1.00	0.79	0.63	0.50	0.40	0.31	0.25
17														
18	**Network/Switch (Network_)**													
19	Power per Capacity per Port	0.03	0.20	W/Gbps/Port		5.0		0.20	0.17	0.15	0.13	0.11	0.10	0.09
20	Cost per Capacity per Port	1.65	10.00	$/Gbps/Port		5.0		10.00	8.71	7.58	6.60	5.74	5.00	4.35
21	Weight per Port	13	20	g/Port		20.0		20	19	19	18	17	17	16
22														
23	**Optical Terminals**													
24	*In-Orbit (OTIO_):*													
25	Max Range of optical Terminal	17236	7000	km	SCOT80	10.0		7000	7502	8041	8618	9237	9899	10610
26	Maximum Datarate	24.6	10.0	Gbps		10.0		10.0	10.7	11.5	12.3	13.2	14.1	15.2
27	Max. Simultaneous Connections	7	3	#	Allow fraction of connecti	10.0		3	3	3	4	4	4	5

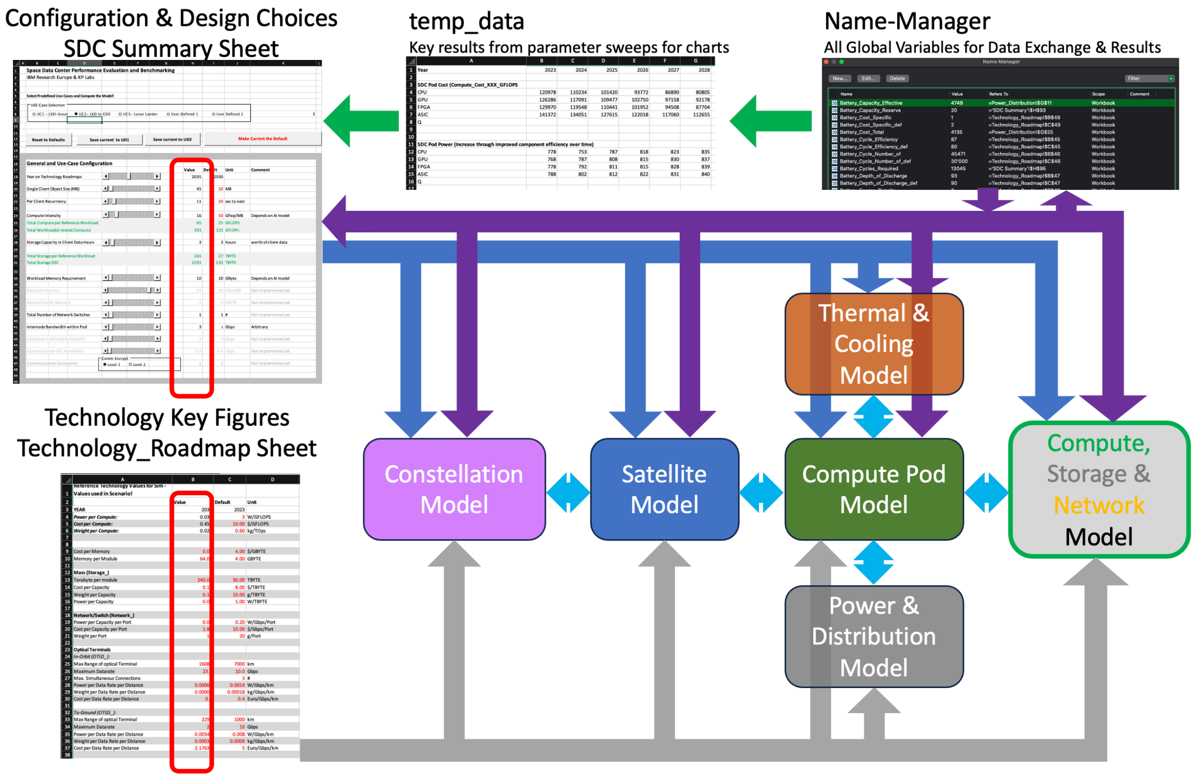
Below row 151 there are additional technology roadmaps which maybe useful for future refinements of the simulator and are provided/left as a reference.

The "Reference Benchmark Section" (Row 75 and following), serves to create a static plot of the SDC Summary sheet on edge-computing cost vs. raw-data-download cost. These numbers are not used anywhere else in the model.

Simulation Model

The simulation model is broken down into 6 different blocks, as outlined in below figure. Starting from the constellation model, requirements are derived or forwarded (the latter by means of “Name-Manager” variables), to the satellite model, which in turn consists of the Power- and Power-Distribution Model, the Thermal and Cooling Model and the Compute Pod Model. The latter then consists of the Compute, Storage and Network model. The latter three are all computed on the “Compute_Storage_Network” sheet.

As depicted in the UI-section of this document, key result sweeps over time can be computed by the press of a button. All results of these sweeps are stored on the temp_data sheet for visualization on the UI. By sweeping over years, most significant “dynamics” of variables are expected to be captured. Arbitrary variables cannot be swept independently yet.



Important:
For such a model to work consistently, a decision had to be made to either start at the compute pod model and then derive power-requirements, which need to propagate through all other model blocks, or vice-versa. The latter was adopted, to maintain our envisioned top-down approach. An overall power- and thermal envelope was defined (by means of the variable ***Power_Total_PV_Capacity*** (SDC Summary, Cell H89), total available power of the solar panels and indirectly an approximation of the overall satellite size) and a usable fraction thereof of made available to supply the Compute Pod. As a result, total available compute power (variable ***SDC_Pod_Compute_Power_Limit***) is one of the results of the model.

SDC_Constellation Sheet

This is the sheet that implements the highest level of the overall simulation model, the “constellation”. It is mainly concerned with orbits, their number of and aggregation values. Most of the latter are not reflected in the primary output of the simulation tool but serve as a reference and are for future use.

This is the summary of the entire Constellation

Requirements from Workloads for individual Satellites ... later also distributed workload requirements

IN

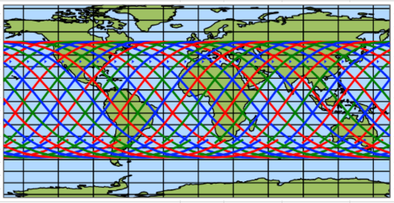
INPUT (link to Workload Requirements)	Value	Unit	Comments
Workload Specifics:			
Workload Compute Requirements	65.45455	GFLOPS	
Workload Memory Requirements	10	GBYTE	
Workload Storage Requirements	265.0909	TBYTE	
Workload Internode BW Estimation	3	Gbbps	
Workload Inter-Satellite BW Estimation	0.5	Gbps	
System/Design Specifics:			
Structural Mass-Fraction	20	%	Could als be TR

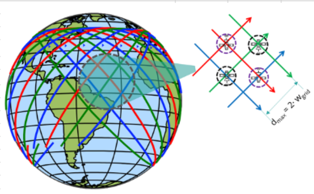
Serves also as kind of an overview...not all values are used here

Technology Roadmap Parameters	Value	Unit	Comments
Launch Cost to GEO per kg	1371.031	Euro/kg	x
Spacing between Satellites	4510	km	o
Inter Satellite Bandwidth	5	Gbps	o
Ground Station Link Length	1000	km	o

Temp

Intermediate Results (Local Satellite-Model)	Value	Unit	Comments
Cost Overview:			
Aggregated Cost per Satellite	306'065	Euro/Dollar	
Launch Cost	192'942	Euro/Dollar	
Number of Satellites	110	#	
NRE (Design, Tools etc.)	2'030'631	Euro/Dollar	
Constellation Deployment Cost	56'921'349	Euro/Dollar	
Performance Overview:			
Aggregated Compute	44'000	GFLOPS	
Aggregated Memory	563'200	GBYTE	
Aggregated Storage	176'000	TERABYTE	
Aggregated Inter-SDC Bandwidth	2'200	Gbps	Assuming 1-4 SDC connections
Aggregated Bandwidth to SDC from Clients	3'300	Gbps	





Out (To SDC Satellite)

Forward To Lower	Value	Unit	Comments
Workload Specifics:			
Workload Compute Requirements	65.4545455	GFLOPS	
Workload Memory Requirements	10	GBYTE	
Workload Storage Requirements	265.090909	TBYTE	
Workload Internode BW Estimation	3	Gbbps	
Workload Inter-Satellite BW Estimation	0.5	Gbps	
System Specifics:			
Structural Mass-Fraction	20	%	

Out (to Overview & (time)Series)			
Aggregated FOMs			
Per Spacecraft (SDC Satellite):			
Compute Capacity	400	GFLOPS	
Memory Capacity	5120	GBYTE	
Storage Capacity	1600	TBYTE	
Aggregated Network Bandwidth External	173	Gbps	
Estimated Power Budget	1847	W	From PV (sunny side)
Total Estimated Weight	141	kg	
Total Estimated Volume	???	m^3	Not implemented yet
Total Estimated BOM Cost	306065	Euro/Dollar	Bill of Material only!!
Launch Cost	192942	Euro/Dollar	
Constellation Specific:			
Total Number of Spacecrafts	110	#	
Non Recurring Cost for Constellation	2'030'631	Euro/Dollar	NOT Ground-Segment
Overall Compute Capability	44000	GFLOPS	
Total Memory Available	563200	GBYTE	
Total Storage Available	176000	TBYTE	
Inter SDC Bandwidth	2200	Gbps	
To SDC Upload Bandwidth	3300	Gbps	
Constellation Deployment Cost Estimate	56921349.4	Euro/Dollar	

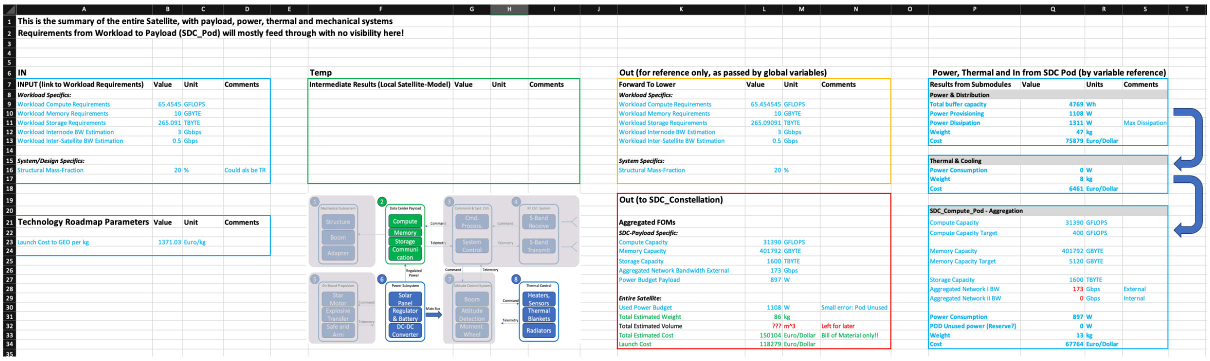
In from SDC Satellite (by global reference)

Results from Submodules	Value	Units	Comments
Aggregated FOMs			
SDC-Payload Specific:			
Compute Capacity	400	GFLOPS	
Memory Capacity	5120	GBYTE	
Storage Capacity	1600	TBYTE	
Aggregated Network Bandwidth E	173	Gbps	
Power Budget Payload	1496	W	
Entire Satellite:			
Estimated Power Budget	1847	W	From PV (sunny side)
Total Estimated Weight	141	kg	
Total Estimated Volume	???	m^3	
Total Estimated BOM Cost	306065	Euro/Dollar	Bill of Material only!!
Launch Cost	192942	Euro/Dollar	

It is thus clear that use-case requirements are “just forwarded” to the model of the individual satellite, as currently considered workload do NOT require distributed computing as required by very large workloads, and exploit constellation properties only for “communication/downlink coverage”, which at this stage is not explicitly modeled or reflected in the FOMs.

SDC_Satellite Sheet

This sheet mainly “forwards” requirements to underlying sub-models (which it does not actively, as all parameters are passed by named (global) variables). Below figure at the right already indicates, that the model first accounts for available power, of which losses in the power-train and buffering power for orbital-night-periods is deduced, then cooling requirements are computed (by underlying model) and finally the remainder of the available power is fed into the compute (SDC_Pod/Compute_Storage_Network) model to get available compute capacity, weight and cost figures. Compute capacity is always “maxed-out” to the available power, with given compute technology and granularity.



This is the summary of the entire Satellite, with payload, power, thermal and mechanical systems
Requirements from Workload to Payload (SDC_Pod) will mostly feed through with no visibility here!

IN

INPUT (link to Workload Requirements)	Value	Unit	Comments
Workload Specifics:			
Workload Compute Requirements	65.4545	GFLOPS	
Workload Memory Requirements	10	GBYTE	
Workload Storage Requirements	265.091	TBYTE	
Workload Internode BW Estimation	3	Gbbps	
Workload Inter-Satellite BW Estimation	0.5	Gbps	
System/Design Specifics:			
Structural Mass-Fraction	20	%	Could als be TR

Technology Roadmap Parameters	Value	Unit	Comments
Launch Cost to GEO per kg	1371.03	Euro/kg	

Temp

Intermediate Results (Local Satellite-Model)	Value	Unit	Comments

Out (for reference only, as passed by global variables)

Forward To Lower	Value	Unit	Comments
Workload Specifics:			
Workload Compute Requirements	65.454545	GFLOPS	
Workload Memory Requirements	10	GBYTE	
Workload Storage Requirements	265.09091	TBYTE	
Workload Internode BW Estimation	3	Gbbps	
Workload Inter-Satellite BW Estimation	0.5	Gbps	
System Specifics:			
Structural Mass-Fraction	20	%	

Out (to SDC_Constellation)

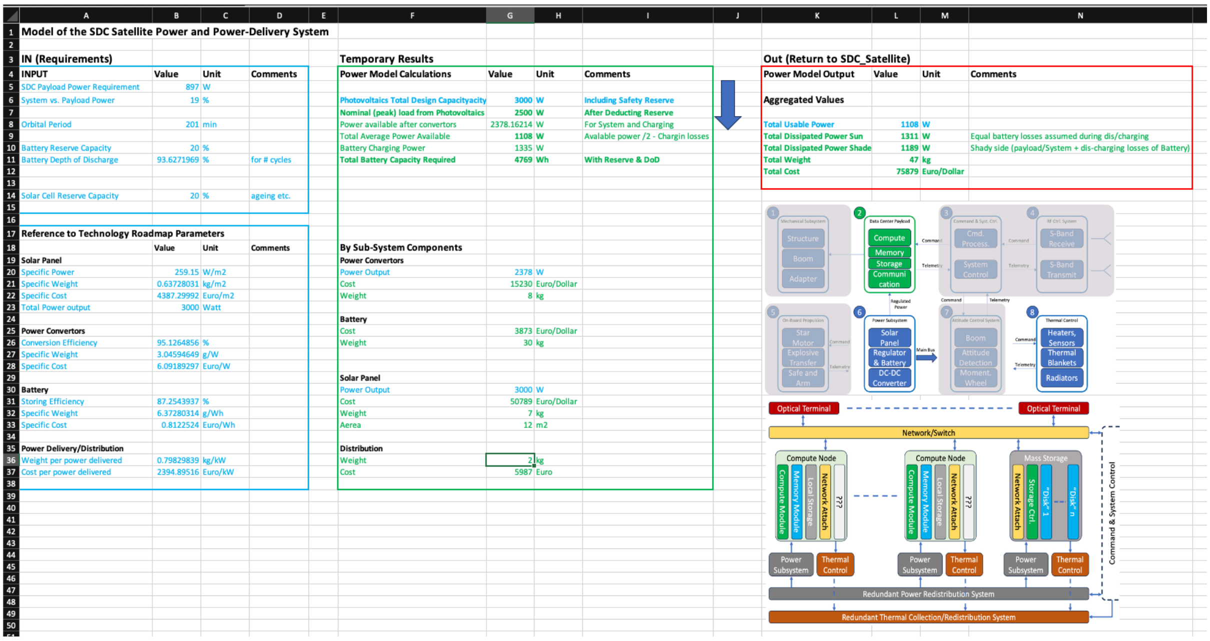
Aggregated FOMs			
SDC-Payload Specific:			
Compute Capacity	31390	GFLOPS	
Memory Capacity	401792	GBYTE	
Storage Capacity	1600	TBYTE	
Aggregated Network Bandwidth External	173	Gbps	
Power Budget Payload	897	W	
Entire Satellite:			
Used Power Budget	1108	W	Small error: Pod Unused
Total Estimated Weight	86	kg	
Total Estimated Volume	???	m^3	Left for later
Total Estimated Cost	150104	Euro/Dollar	Bill of Material only!!
Launch Cost	118279	Euro/Dollar	

Power, Thermal and In from SDC Pod (by variable reference)

Results from Submodules	Value	Units	Comments
Power & Distribution			
Total buffer capacity	4769	Wh	
Power Provisioning	1108	W	
Power Dissipation	1311	W	Max Dissipation
Weight	47	kg	
Cost	75879	Euro/Dollar	
Thermal & Cooling			
Power Consumption	0	W	
Weight	8	kg	
Cost	6461	Euro/Dollar	
SDC_Compute_Pod - Aggregation			
Compute Capacity	31390	GFLOPS	
Compute Capacity Target	400	GFLOPS	
Memory Capacity	401792	GBYTE	
Memory Capacity Target	5120	GBYTE	
Storage Capacity	1600	TBYTE	
Aggregated Network I BW	173	Gbps	External
Aggregated Network II BW	0	Gbps	Internal
Power Consumption	897	W	
POD Unused power (Reserve?)	0	W	
Weight	13	kg	
Cost	67764	Euro/Dollar	

Power_Distribution Sheet

This model is based on assumptions of conversion efficiency, battery technology (e.g. depth of discharge [DoD]) and orbital parameters (duration of night -> battery capacity required). The sub-model key output is available power to the compute pod and cost and weight of the battery, solar panel, and power-conversion systems.



Model of the SDC Satellite Power and Power-Delivery System

IN (Requirements)

INPUT	Value	Unit	Comments
SDC Payload Power Requirement	897	W	
System vs. Payload Power	19	%	
Orbital Period	201	min	
Battery Reserve Capacity	20	%	
Battery Depth of Discharge	93.6271969	%	for # cycles
Solar Cell Reserve Capacity	20	%	ageing etc.

Reference to Technology Roadmap Parameters	Value	Unit	Comments
Solar Panel			
Specific Power	259.15	W/m2	
Specific Weight	0.63728031	kg/m2	
Specific Cost	4387.29992	Euro/m2	
Total Power output	3000	Watt	
Power Convertors			
Conversion Efficiency	95.1264856	%	
Specific Weight	3.04594649	g/W	
Specific Cost	6.09189297	Euro/W	
Battery			
Storing Efficiency	87.2543937	%	
Specific Weight	6.37280314	g/Wh	
Specific Cost	0.8122524	Euro/Wh	
Power Delivery/Distribution			
Weight per power delivered	0.79829839	kg/kW	
Cost per power delivered	2394.89516	Euro/kW	

Temporary Results

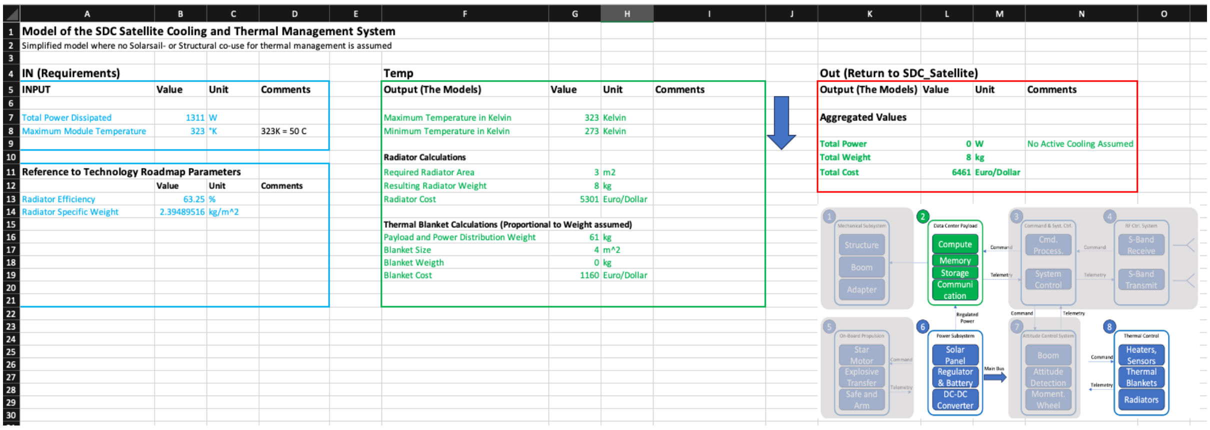
Power Model Calculations	Value	Unit	Comments
Photovoltaics Total Design Capacityacity	3000	W	Including Safety Reserve
Nominal (peak) load from Photovoltaics	2500	W	After Deducting Reserve
Power available after convertors	2378.16214	W	For System and Charging
Total Average Power Available	1108	W	Avalable power /2 - Chargin losses
Battery Charging Power	1335	W	
Total Battery Capacity Required	4769	Wh	With Reserve & DoD
By Sub-System Components			
Power Convertors			
Power Output	2378	W	
Cost	15230	Euro/Dollar	
Weight	8	kg	
Battery			
Cost	3873	Euro/Dollar	
Weight	30	kg	
Solar Panel			
Power Output	3000	W	
Cost	50789	Euro/Dollar	
Weight	7	kg	
Aerea	12	m2	
Distribution			
Weight	2	kg	
Cost	5987	Euro	

Out (Return to SDC_Satellite)

Power Model Output	Value	Unit	Comments
Aggregated Values			
Total Usable Power	1108	W	
Total Dissipated Power Sun	1311	W	Equal battery losses assumed during dis/charging
Total Dissipated Power Shade	1189	W	Shady side (payload/System + dis-charging losses of Battery)
Total Weight	47	kg	
Total Cost	75879	Euro/Dollar	

Thermal_and_Cooling Sheet

The main contribution of this sub-model is the derivation of the cooling requirements, mostly weight, secondary also cost, to be able to operate at the given power-envelope. Only less than half of what the solar panels provide at peak, will be available for satellite system and payload operation, as the other half is needed to re-charge the batteries, such that the satellite is always operational, irrespective of day- or night-time. While this may be questioned, as the majority of observation-data is acquired during daytime, our assumption constitutes the most generic scenario, which with emerging hyper-spectral and SAR sensors will become more relevant. Also, any node in the constellation may be assigned tasks, such as compute and communication, irrespective of solar exposure, i.e. where they are w.r. to their orbital cycle.

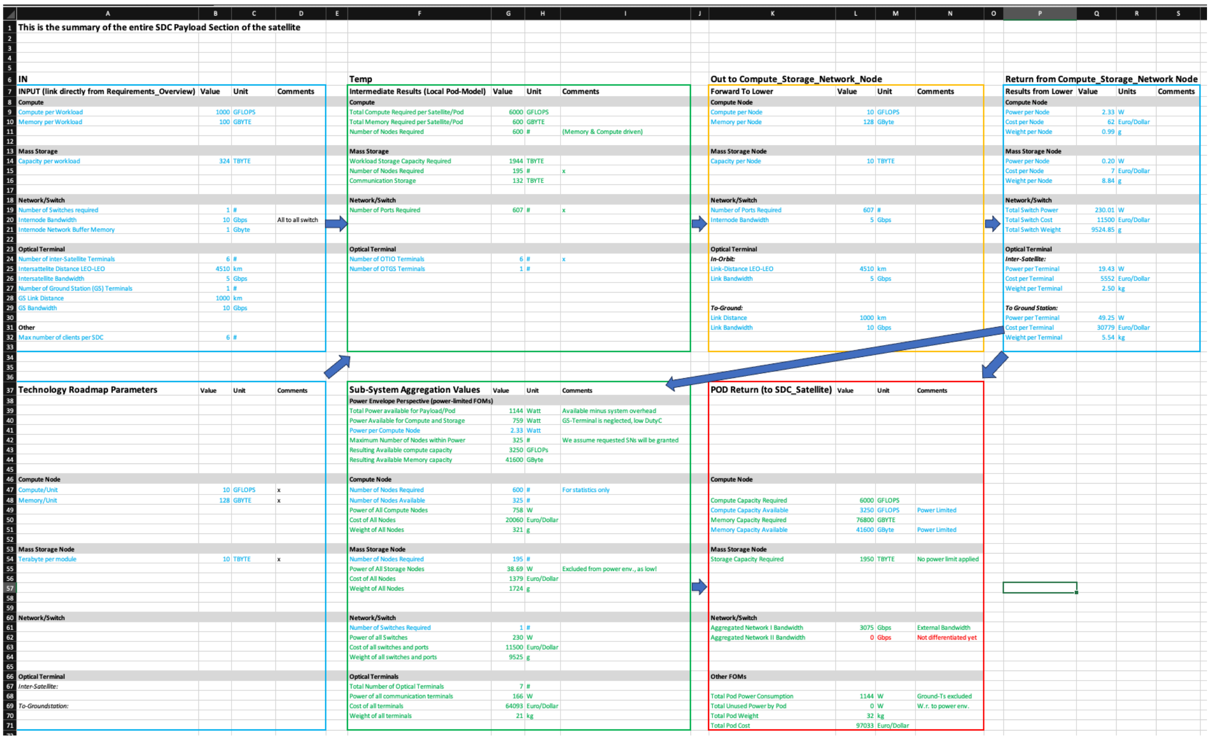


SDC_Pod Sheet

In this sub-model, satellite requirements are broken down into node requirements (we assume here a single compute pod (i.e. the compute payload), with several/many nodes. For future scenarios with larger satellites, this approach can be extended towards several pods per satellite too.

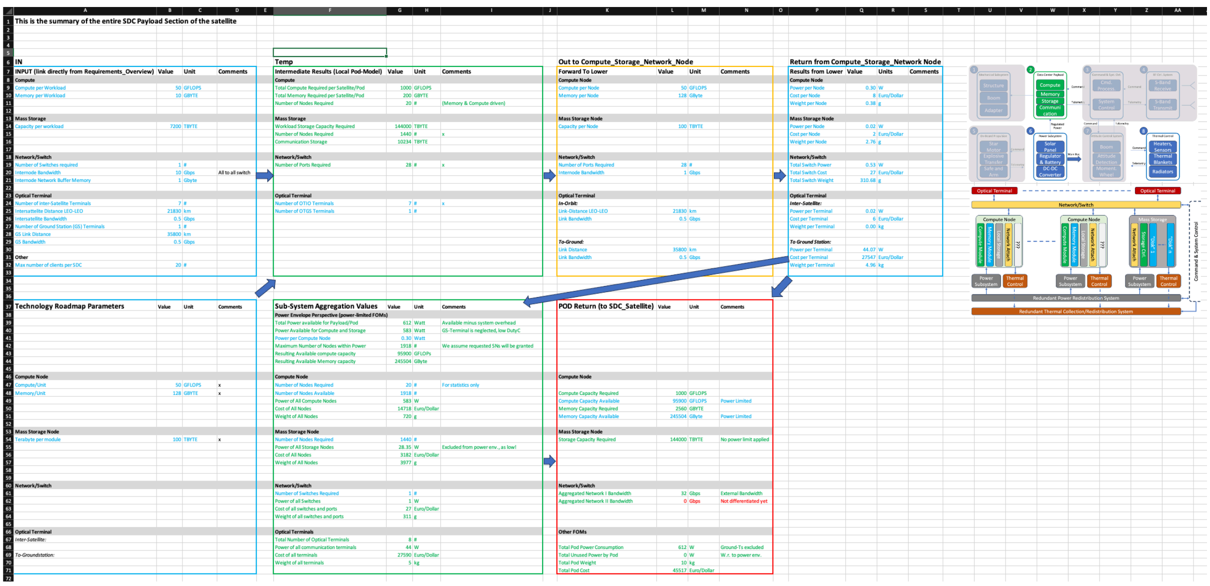
As indicated with arrows, from workload/satellite requirements, the node-requirements are derived and provided to the "***Compute_Storage_Network***" model, where compute capacity, network and communication performance is computed according to available (power) resources.

The results from the latter are then aggregated to satellite level and returned to "***SDC_Satellite***" (again by means of global variables.



Compute_Storage_Network Sheet

This sub-model is key for the entire model. Never-the-less, the actual models of the compute node, communication terminals etc. are very simple and consist mainly of multiplying the node-requirements with the “efficiency” (power specific compute, weight specific compute etc.) numbers from the technology roadmap.



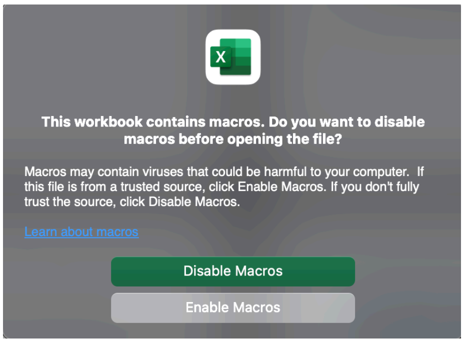
As the numbers from this sheet significantly affect the overall results through scaling, the user should ensure that they represent his/her study-intent.

Example System Analysis

In this section, a step-by-step use of the system simulator is executed to guide the user through all necessary steps. The application is run on an apple Macintosh (OSX Sonoma 14.3.1). As Microsoft Excel has a reduced functionality on OSX compared to Windows operating systems, we assume the user-experience on Windows should be equal or better.

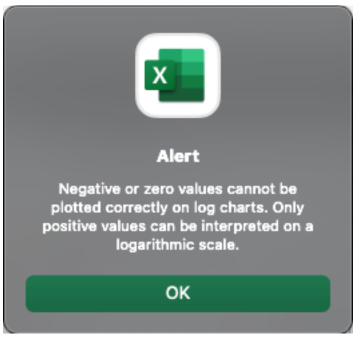
1. Open the Spreadsheet

Open the spreadsheet file and allow running macros, otherwise the simulator cannot function properly:

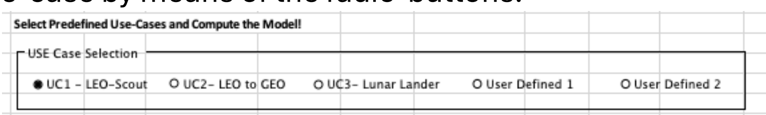


2. Select the Use Case

Open the **SDC Summary** sheet, if not already open. As many charts use log-scale, it is likely you will eventually be presented with Alerts. You can safely acknowledge them.



Now select a use-case by means of the radio-buttons.



For this example we will stick with Use-Case 1. To be sure, press the radio button again. This loads all configuration parameters into the active value column ***SDC Summary*** H.

3. Verify and adjust individual settings

It's always good to quickly move the year 1 forward and 1 backward, this assures all values from the technology roadmap are properly copied into the active "value" column.

General and Use-Case Configuration		Value	Default	Unit	Comment
		Value	Default	Unit	Comment
Year on Technology Roadmaps		2030	2030		

While the use-case properly assigns the top-level architecture in the value-column, you may want to select the corresponding top-level architecture also from the radio-button, as it was not possible to have it automatically update the button position. Of course, you can change the architecture if you want, but it only marginally affects the results (see comments in cells).

Design & Technology Decisions					
Architecture & Constellation Parameters					
	TLA		Default	Unit	Comment
Toplevel Architecture	O Scout O LEO-GEO ● Lunar Lander	Scout	LEO-GEO		See SDC_Satellite L34, E_S_N G22-24
					USE "Scout" for ALL LEO applications

The same applies for the Radio-button of the compute type…just confirm the value in the "value" column or select another compute type. This will of course affect your results clearly!

4. Recompute the Sweeps

Now everything is ready to recompute all the parameter sweeps, so press the large button. As indicated, this may take a moment to complete. During the computation, you will be brought to the ***Technology_Roadmap*** sheet. The entire "value" column will change all the time, in column "G" the compute type may vary occasionally, but mainly you will be able to monitor progress by looking at the "Year" in the value column, which iterates from 2023 to 2050. Upon completion you will be brought back to the ***SDC Summary*** sheet.

	A	B	C	D	E	F	G	H	I	J
1	Reference Technology Values for Sim - Values used in Scenario!						YEAR	2023	2024	20
2		Value	Default	Unit		Performance Doubling Every XY Years				
3	YEAR	2030	2023			red = exponential, yellow = linear				
4	*Power per Compute:*	0.233	3	W/GFLOPS		1.9	GPU	3.00000	2.08298	1.446
5	*Cost per Compute:*	1.647	10.00	$/GFLOPS		2.7	GPU	10.00	7.73	5.
6	*Weight per Compute:*	0.099	0.60	kg/TOps		2.7	GPU	0.60	0.46	0.
7										
8										
9	Cost per Memory	0.35	4.00	$/GBYTE		2.0		4.00	2.83	2.
10	Memory per Module	20.16	4.00	GBYTE		3.0		4.00	5.04	6.
11										
12	Mass (Storage_)									
13	Terabyte per module	100.91	30.00	TBYTE		4.0		30.00	35.68	42.
14	Cost per Capacity	0.71	8.00	$/TBYTE		2.0		8.00	5.66	4.

To update the "red dot" in the figures, cycle again one up/down on the YEAR slider. Now you can inspect all relevant quantities in the charts and in the green field.

Key Figures of Merit			
			Delta to Use Case Requirement Red means lack of resource!
Year of Simulation	2030		N.A.
Selected Use Case	Use-Case 1		N.A.
Type of Compute on Satellite	GPU		N.A.
Power on Satellite	3000	Watt	
Weight per Satellite	96	kg	
Cost per Satellite (incl. Launch)	316'257	Euro	
Cost per TOps	99	Euro/$	
Power per Compute	0.94	Watt/TOps	
Cost per Power	105'419	Euro/Kilowatt	
Inter-SDC P2P bandwidth	2352.6	Gbitps	N.A.
SDC Node Aggregated Compute (Fully exploiting available power)	3.20	TFLOps	0.9
SDC Memory Req.	10'240	Gbyte	2912
Power for Compute Payload	935	Watt	N.A.
Power for Communication	10	Watt	N.A.
Battery Required vs. Available cycles	13'045	#	25191

In case you get some red numbers in the green field, you can play with all values in the value column in the configuration section (either by slider action or by inserting values directly). This will recompute the model and the figures of merit as displayed above, for the values from the technology roadmap, corresponding to the year selected at the top of the configuration section.
If you have found some settings which seem promising, you should re-run the Recompute sweep to understand how the changes affect the key results over time.

5. Experiment with the Interactive dependency/sensitivity analysis

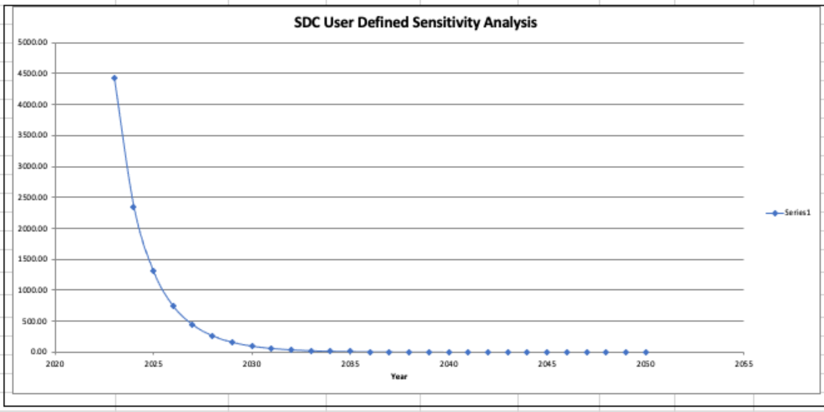
This window is kind of experimental. It allows you to plot many quantities that were computed during the parameter sweep against each other.
It is important to note, that time (i.e. year) is the curve parameter, meaning that they are not sweeps of two parameters against each other, everything else fixed, but always an implicit function of time. All values plotted origin from the ***temp_data*** sheet and were computed during the main sweep.

Interactive Dependency Study

Maybe need to clean-up/delete Graph from time to time, as new graphs will be created on top of each other!

Select Trace to display

☐ SDC Pod Cost [Euro]	FALSE
☐ SDC Pod Power [Watt]	FALSE
☐ SDC Pod Weight [kg]	FALSE
☐ SDC Satelliute Weight [kg]	FALSE
☐ Payload to Weight Ratio [kg/kg]	FALSE
☐ Compute per Pod [GOPs]	FALSE
☐ SDC Pod Memory [Gbyte]	FALSE
☐ Compute per Sat. Weight [TOps/kg]	FALSE
☐ Cost per Satellite Weight [Euro/kg]	FALSE
☑ Cost per TeraOps Compute	TRUE
☐ Power per TeraOps	FALSE
☐ Cost per Power	FALSE
☐ Custom Data	FALSE



Independent Variable

1 ● YEAR ○ SDC Pod Cost ○ SDC Pod Power ○ SDC Pod Weight ○ SDC Satellite Weight ○ Payload Weight Ratio ○ Compute per Pod ○ SDC Pod Memory

○ Compute per Sat Weight ○ Cost per Sat Weight ○ Cost per TeraOps ○ Power per TeraOps ○ Cost per Power ○ CUSTOM

Select Compute Type

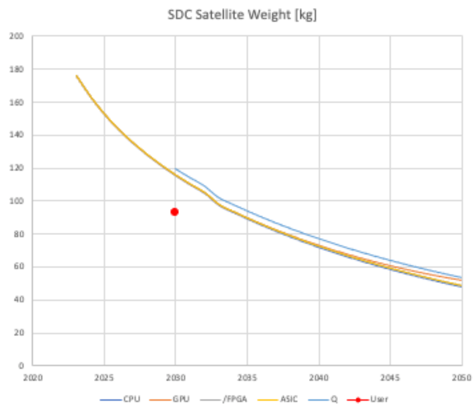
2 ○ CPU ● GPU ○ FPGA ○ ASIC ○ Quantum

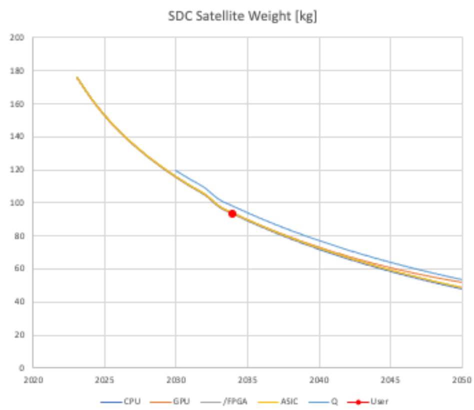
CUSTOM DATA	Lower Bound	Upper Bound	Increment
"Power_Total_PV_(	1000	5000	137.9
This section not implemented yet			

Solving Issues and known limitations and tips

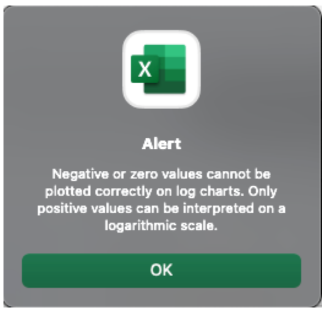
As with every software tool, even more with research grade or early release tools, it is not possible to fully suppress all errors or misbehaviors. This section gives the user guidance on how to deal with potential issues and where to look for fixing them.

1. Problem: The actual value “red-dot” is NOT on the trace in the graph
   Cause: The curves may have been computed/swept with different requirements values. This happens e.g. when in **Section 1** the Use-Case is changed.
   Solution:
    a. Often a quick click on the year up/down solves the problem
    b. If the problem persists, the sweeps may have to be recomputed to represent the current combination of requirements and technology roadmaps
    c. It may be necessary to re-confirm the radio-button selections in Section 1,



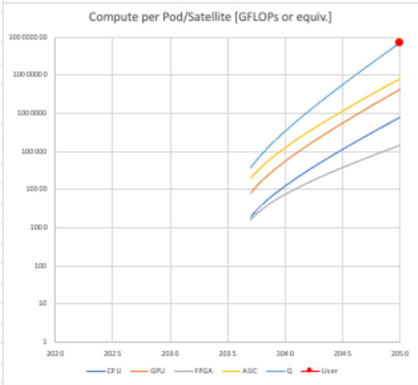


2. Problem: Sometimes when applying changes, Excel complains about negative values for logarithmic charts.
   Cause: On rare occasions, the system model may result in “0” values which cannot be properly plotted on logarithmic charts.
   Solution: In our experience, these errors can at the current stage be ignored and “clicked-away”.



3. Problem: #REF (Reference Missing) in Section 5 (or on other pages)
   Cause: This may be caused by some mismatch between functions for different use-cases that are not yet captured in the VBA code.
   Solution: Check if any result is affected. Report the error (maybe save current configuration to one of the user-scenarios for sharing with the development team.

4. Problem: Incomplete Graphs



Cause: Some of the numbers in ***temp_data*** are negative, thus cannot be plotted on a log-plot. This can e.g. happen in the GEO case, when too much power is needed for communication and no power is left for compute, thus "negative" compute power would result (we tried to capture this with simple code though).
Solution: Either increase the power-envelope, reduce communication requirements or other power-consumers.

5. Problem: List of all named ranges/variables on the ***Workbook_Variables*** sheet is no longer up to date.
   Cause: You have added or removed variables.
   Solution: Select cell A1 in ***Workbook_Variables,*** Under "Formulas" -> Use in Formulas -> Paste Names -> (scroll to the bottom) Paste List ... and you will get an up to dated list of all named ranges/variables used in the workbook and in which cell they are defined.

6. Tip: Open multiple windows of the same workbook: Sometimes it's helpful to see how changes in one sheet affect other sheets.
   Cause: Too many sheets per workbook.
   Solution: In the Window-Menu select New Window. This opens a new window of the same sheet. In the latter you can navigate to any sheet and changes in another sheet will be immediately visible to you.

Administrative

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