



Supplement of

The ECOSENSE forest: a distributed sensor and data management system for real-time monitoring of ecosystem processes and stresses

Jasmin Tesch et al.

Correspondence to: Jasmin Tesch (jasmin.tesch@hydrology.uni-freiburg.de) and
Kathrin Kühnhammer (kathrin.kuehnhammer@ecosense.uni-freiburg.de)

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Table S1

Bill of Material (BoM) ECOSENSE forest

☉ Application	Type	Manufacturer	Manufacturer's Country	Model	Description	Comment
Power	DC/DC-Converter	MEAN WELL ENTERPRISES CO., LTD.	Taiwan	DDR-120C-12	120W, 12V, 10A Isolated	Convert from 48V to 12V Isolated
Power	DC/DC-Converter	MEAN WELL ENTERPRISES CO., LTD.	Taiwan	DDR-120C-24	120W, 24V, 5A Isolated	Convert from 48V to 24V Isolated
Power	DC/DC-Converter	MEAN WELL ENTERPRISES CO., LTD.	Taiwan	DDR-30L-5	30W, 5V, 6A	Convert from 48V to 5V
Power	DC/DC-Converter	MEAN WELL ENTERPRISES CO., LTD.	Taiwan	DDR-240C-24	240 W, 24 V, 10 A, Isolated	Convert from 48V to 24V Isolated
Power	Power supply	MEAN WELL ENTERPRISES CO., LTD.	Taiwan	MW NDR-480-48	230V power supply, 48V, 10A	Cost efficient, high Power AC/DC power supply for distribute 48V to the fieldside
Power	Power supply	MEAN WELL ENTERPRISES CO., LTD.	Taiwan	MW NDR-120-48	230V power supply, 48V, 2.5A	Cost efficient, high Power AC/DC power supply for distribute 48V to the fieldside
Power	Power supply	MEAN WELL ENTERPRISES CO., LTD.	Taiwan	RSP-2400-48	2400W, 48V, 50A	Convert from 230V AC to 48V DC powerall for the fieldside.
Power	Powermeter	Shelly Group SE	Bulgaria	Pro 4PM	Powermeter, 4 channel, internal switch, Ethernet, Wifi	Powermeter with ethernet and API for remote control (on/off) and monitor power consumed.
Power	Cable	U.I. Lapp GmbH	Germany	Ölflex Classic 110	4x1,0 qmm, UV resistance, oil resistance	Ölflex Classic 110 was our standard cable for the 48V/24/12V power wiring in in various cross-sections depending on the current strength. It withstands the sun well, and animals usually ignore it.
Power	Cable	U.I. Lapp GmbH	Germany	4521021	Flex cable H07V-K 1 x 25 mm² blue 50 m	Cost efficient, flexible high power cable, no UV resistance. Distributes high current 48V to the towers.
Power	Plastic pipe	FRÄNKISCHE Rohrwerke Gebr. Kirchner GmbH & Co. KG	Germany	FBY-EL-F 25	Plastic corrugated pipe, 25mm	Plastic pipe to protect wire from sun and animals.
Power	Housing	BOXPERT DE Breuell Ingenieurbüro GmbH	Germany	FLT 400300170 TR	Wallhousing IP65, 300 x 400 x 170 mm, transparent	Wall mounted basic housing.
Power	Isolation (Heat)	NMC GmbH	Belgium	INSUL ROLL XT	19mm, Closed-cell foam based on rubber	19mm isolation for measurement container, water proof, self-adhesive.
Power	Cable	Kabel-Werk GmbH u. Co. KG	Germany	NYCWY	NYCWY 4x25RM/16, underground cable	High voltage, high current underground cable for our 3 phase 230V powerline to the measurement container (650m) > 10kw.
Network	Server	WORTMANN AG	Germany	MinServer G5	Xeon E-2356G, 64GB DDR4 ECC / 2TB SSD / 4TB HDD	Hosts virtual machines (VMs), Fieldside Datastorage
Network	Ethernet to COAX converter	AXING AG	Switzerland	EOC00132	1800 Mbps, 500m peer to peer netork	Converts ethernet to coax and back for 450m distance.
Network	PoE Switch	TRENDnet, Inc.	United States	TL-PE80	8-Port PoE Switch, unmanaged, 10/100 Mbit	Cost efficient 8 Port PoE switch.
Network	Patchcable	Tragant Handels- und Beteiligungs GmbH	Germany	80250	Outdoor Patchcable, cat7, S/FTP, 3m	Cost efficient, high speed, outdoor patchcable.
Network	Wifi Accespoint	TP-Link Corporation PTE. Ltd	Singapore	Deco X50 Outdoor	IP65, 5GHz, 2.4Ghz, Mesh, PoE, 3000 Mbit/s Accespoint	Cost efficient IP65 Outdoor Wifi accespoint with PoE.
Network	Ethernet Switch	Ubiquiti Inc.	United States	USW-24	Managed ethernet switch, 24 Port RJ45, 2 Port SFP	Managed ethernet switch for UniFi environment. Perfect for remote access.
Network	Satellite communication	Starlink Internet Services Limited	United States	Standard-Kit Gen. 3	200Mbits, Satellite communication, with Wifi Router Gen. 2	200 Mbit download and 20 Mbit upload satellite communication system.
Network	Ethernet Adapter	Starlink Internet Services Limited	United States	Ethernet Adapter	Adapter cable for Ethernet, 1Gbits	Adapter cable for the Starlink Gen. 2 Router.
Network	VPN Gateway	Fortinet, Inc.	United States	Fortinet FortiGate 40F	VPN Gateway	VPN gateway to manage VPN tunnel to University Freiburg (license required).
Network	Cable	ASSMANN WSW components GmbH	Germany	DK-1741-VH-10-OD	Ethernet cable, CAT 7, S-FTP, Outdoor	Standard ethernet cable for outdoor or underground network wiring.
Network	Ethernet Switch	D-Link Systems, Inc.	Taiwan	DGS-1100-10MPV2	PoE, 10 Port managed Switch, SFP+	PoE Switch for powering devices, connected via SFP+ and LWL to the network.
Network	Ethernet Switch	Ubiquiti Inc.	United States	USW-Ultra (42W)	PoE, 8 Port managed Switch	Very compact PoE switch, can be controlled using the UniFi Management Tool. Very good
Network	Ethernet surge protectors	Ubiquiti Inc.	United States	ETH-SP-G2	Lightning protection for Ethernet	Protects the data line from overvoltage
Network	LoRa Gateway	Milesight Ltd.	United Kingdom	UG67-L04EU-868M	PoE, LoRa Gateway	Customizable LoRa gateway, power supply via Ethernet with PoE
Software	UniFi Server	Ubiquiti Inc.	United States	9.0.108	open-source	Manages UniFi devices on the fieldside. Runs as a service on the Windows server.
Software	Aquarius	Aquatic Informatics ULC	Germany	Aquarius Time-Series V25.1.69.0	commercial	Stores fieldside metadata such as power consumption or temperature in the measurement container. Some sensors also store their data there via Wi-Fi/LoraWAN.
Software	Influx	InfluxData Inc.	United States	InfluxDB v2.7.5	open-source	Stores fieldside metadata such as power consumption or temperature in the measurement container. Some sensors also store their data there via Wi-Fi/LoraWAN.

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Software	Grafana	Grafana Labs Inc.	United States	v11.5.1	open-source	Used to visualize data. Data comes from Influx and Aquarius. Dashboards and alerts are created from data manager.
Software	Telegraf	InfluxData Inc.	United States	Version 1.29	open-source	Tool to connect Influx to different datasources like a MQTT broker
Software	Windows Server 2022 Standard	Microsoft Corporation	United States	21H2	commercial	Windows Server version with Hyper Visor
Software	MQTT Mosquito	Eclipse Foundation AISBL	United States	2.0.18	open-source	Free to use, light weight MQTT Broker for Win, Linux
Software	Node-RED	OpenJS Foundation	United States		open-source	
Software	The Things Network	The Things Industries	United States		commercial	

Table S2

Sensor Inventory ECOSENSE forest

☉ Type	Description	#	Quantity (today)	Manufacturer	Manufacturer's Country	Model	Ecosystem compartment	Associated with ... (where applicable)
System	Gas Analyser		1	Agilent Technologies, Inc.	United States of America	CP2002	Above soil/below ground	
Sensor	2-D Sonic anemometer		1	Campbell Scientific, Inc.	United States of America	Windsonic	Open area (parking lot)	
Sensor	3-D Sonic anemometer		1	Campbell Scientific, Inc.	United States of America	CSAT3B	Above-canopy platform	Eddy covariance system
Sensor							Above-canopy platform + Tower platforms in the tree canopy + Below canopy	
Sensor	Air Temperature and humidity		10	Campbell Scientific, Inc.	United States of America	HygroVUE10	Open area (parking lot)	
Sensor	Air Temperature and humidity		1	Campbell Scientific, Inc.	United States of America	HygroVUE5	Above-canopy platform	
Sensor	All-in-One Weather sensor		1	Campbell Scientific, Inc.	United States of America	ClimaVUE50	Below-canopy	
Sensor	Barometer		1	Campbell Scientific, Inc.	United States of America	BaroVUE10	Below-canopy	
System	Eddy covariance system		1	Campbell Scientific, Inc.	United States of America	IRGASON	Below-canopy	
Sensor	Present weather sensor		1	Campbell Scientific, Inc.	United States of America	CS125	Above-canopy platform	
Sensor	Soil temperature		3	Campbell Scientific, Inc.	United States of America	CS107	Below ground	
System	REA (Relaxed Eddy Accumulation) system (EC system + self-developed system)		1	Campbell Scientific, Inc. + developed by ECOSENSE	United States of America	IRGASON	Above-canopy platform	
System	REA (Relaxed Eddy Accumulation) system (EC system + self-developed system)		1	Campbell Scientific, Inc. + developed by ECOSENSE	United States of America	IRGASON	Below-canopy	
System	Digital Hemispherical Photography		1	Canon Inc. + Sigma Corporation	Japan	EOS 700D + Sigma 4.5 mm f/2.8 EX DC	Above soil	
Sensor	Tipping Bucket		18	Davis Instruments, Corp.	United States of America	D7852 TBRG	Above-canopy platform + Below-canopy + Tree stems	
Sensor	Soil moisture sensor		7	Delta-T Devices, Ltd.	United Kingdom	ML2e	Below ground	
Sensor	Chlorophyll fluorescence sensor		22	developed by ECOSENSE	Germany		Tree leaves	
Sensor	Dendrometer		33	developed by ECOSENSE	Germany		Tree stems	
System	ECovette		27	developed by ECOSENSE	Germany		Tree leaves	In-situ leaf gas exchange system
System	In-situ leaf gas exchange system		3	developed by ECOSENSE	Germany		Tower platform in the tree canopy + Container	
System	Infiltration sampler		60	developed by ECOSENSE	Germany		Ground level	
Sensor	PAR sensor		80	developed by ECOSENSE	Germany	-	Tree leaves	In-situ leaf gas exchange system
Sensor	Gradient soil probe		3	developed by ECOSENSE	Germany		Below ground	
System	Temperature profile probe		3	developed by ECOSENSE	Germany		Above & Below Ground	
System	CO ₂ multisensor-probe		1	developed by ECOSENSE	Germany		Above & Below Ground	
System	Needle cuvettes		22	developed by ECOSENSE	Germany		Tree leaves	In-situ leaf gas exchange system
Sensor	Soil matrix potential sensor		6	ecoTech Umwelt-Messsysteme GmbH	Germany	pF-Meter	Below ground	
Sensor	Soil matrix potential sensor		12	ecoTech Umwelt-Messsysteme GmbH	Germany	Tensiometer	Below ground	
System	Terrestrial laser scanner		4	Environmental Sensing Systems	Australia	LEAF MkIII	Above soil	
Sensor	Microtensiometer		18	FloraPulse Co.	United States of America	FloraPulse Analog	Tree stems	
Sensor	MicroPAM		6	Heinz Walz GmbH	Germany	MICRO_HEAD/3B	Tree leaves	Commercial chlorophyll fluorescence measurements
Sensor	PAR sensor		12	Heinz Walz GmbH	Germany	LS-C	Tree leaves	
Sensor	Heat flux plate		3	Hukseflux Thermal Sensors B.V.	Netherlands	HP01SC-L	Below ground	
System	Spectroradiometric chlorophyll fluorescence system		1	JB Hyperspectral Devices GmbH	Germany	FLOXBOX	Above-canopy platform	
Analyzer	CO ₂ /H ₂ O analyzer		3	LI-COR, Inc.	United States of America	LI-850	Tower platforms in the tree canopy + Container	In-situ leaf gas exchange system, Gradient system
System	Eddy covariance system		1	LI-COR, Inc.	United States of America	LI7200/RS + SmartFlux 2	Above-canopy platform	

Table S2

Sensor Inventory ECOSENSE forest

Sensor	PAR sensor	2	LI-COR, Inc.	United States of America	LI-190	Above-canopy platform	
Sensor	Net radiation (shortwave + longwave)	2	OTT HydroMet, Corp.	Netherlands	CNR4	Above-canopy platform + Open area (parking lot)	
Sensor	Pyranometer	6	OTT HydroMet, Corp.	Netherlands	CM11, CM21	Ground level	
Sensor	Pyranometer	2	OTT HydroMet, Corp.	Netherlands	CM21	Above-canopy platform	Suntracker
Sensor	Pygeometer	1	OTT HydroMet, Corp.	Netherlands	CG1	Above-canopy platform	Suntracker
Sensor	Pyrheliometer	1	OTT HydroMet, Corp.	Netherlands	CHP1	Above-canopy platform	Suntracker
System	Suntracker	1	OTT HydroMet, Corp.	Netherlands	SOLYS2	Above-canopy platform	
Analyzer	Isotope analyzer	1	Picarro, Inc.	United States of America	G2131-I Isotopic Analyzer	Container	In-situ leaf gas exchange system, Gradient system
Sensor	CO2 sensor	8	Process Sensing Technologies Ltd.	United Kindom	Platinum Series Carbon Dioxide Sensor	Below ground	
Sensor	Tipping Bucket	2	R. M. Young Company	United States of America	Young52202	Above-canopy platform + Open area (parking lot)	
Sensor	Wind speed and direction	1	R. M. Young Company	United States of America	Young05103	Above-canopy platform	
System	PhenoCam	2	StarDot Technologies	United States of America	StarDot NetCam SC IR	Below-canopy + Above-canopy platform	
Sensor	Soil moisture sensor	492	TRUEBNER GmbH	Germany	SWT100	Below ground	
System	Leaf angle cameras	26	Ubiquiti Inc.	United States of America	UVC-G5-Bullet	Below-canopy	
Sensor	Sap flow Sensors	58	Umwelt-Geräte-Technik GmbH	Germany	SFM-5	Tree stems	
Sensor	Optical dendrometer (CavCam)	6	University of Tasmania	Australia	CavCam	Tree branches	
Sensor	Ceillometer	1	VAISALA Oyj.	Finland	CL31	Open area (parking lot)	
Sensor	CO2 sensor	17	VAISALA Oyj.	Finland	GMP343	Above soil + Below ground	
System	Moni-DA	1	Heinz Walz GmbH	Germany		Tower platform in the tree canopy	Commercial chlorophyll fluorescence measurements
System	Microcontroller platform	100	developed by ECOSENSE	Germany		Tree branches	