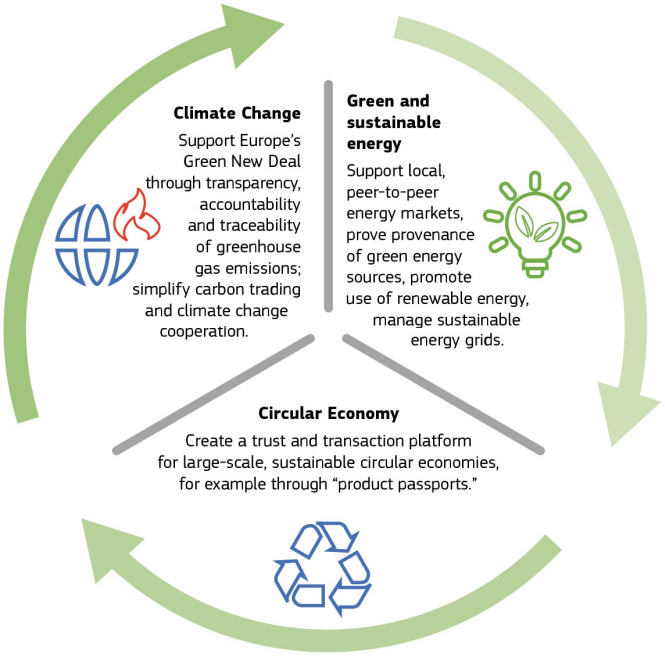
Electricity sector digitalisation and blockchains

Gianluca FULLI, PhD
Deputy Head of Unit
Energy Security, Distribution and Markets
European Commission - Joint Research Centre

PhD course energy security and sustainability
Politecnico di Torino, 2021

1

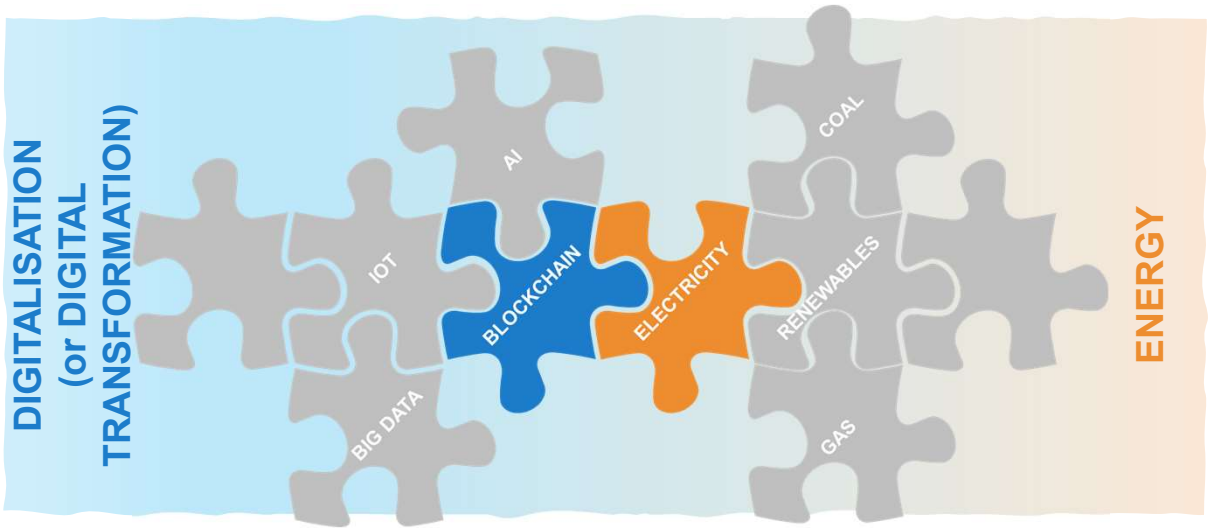
Blockchain key technology for sustainability?



2 https://digital-strategy.ec.europa.eu/en/library/european-blockchain-strategy-brochure#:~:text=The%20EU%20Blockchain%20Observatory%20%26%20Forum,in%20this%20transformative%20new%20technology

2

What we will focus on



3

3

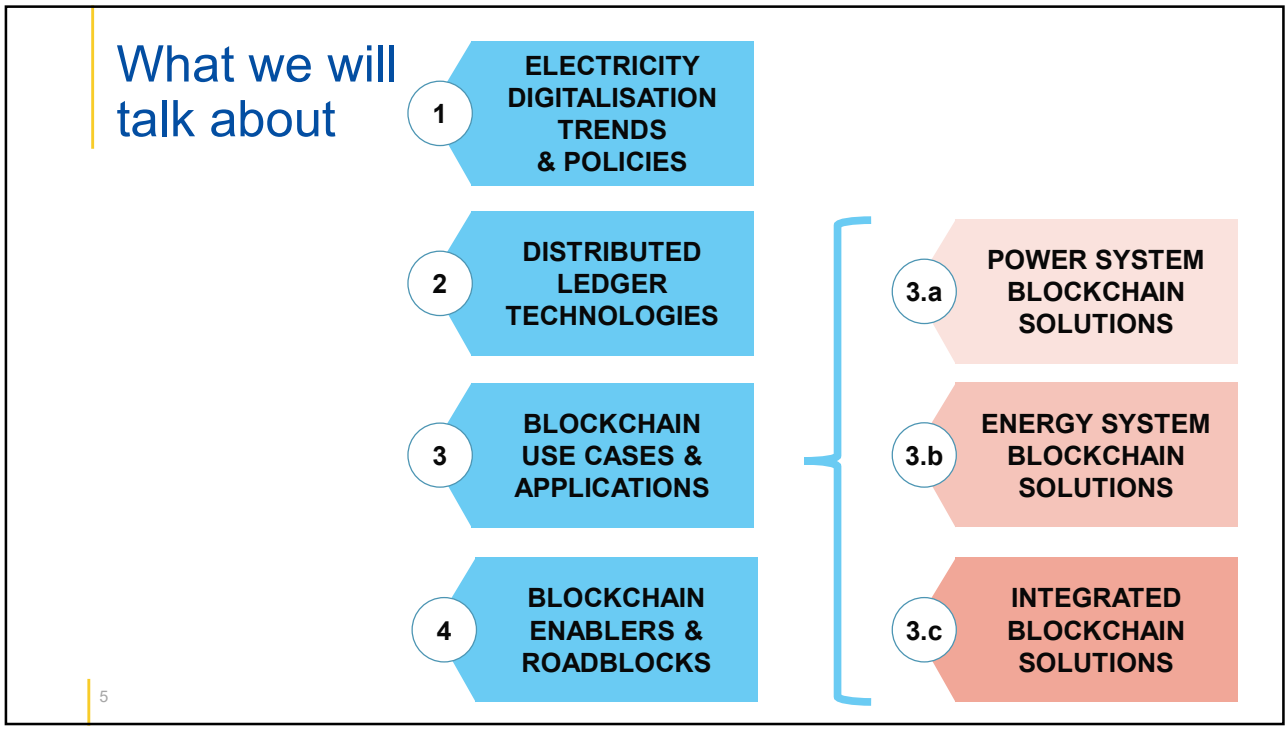
Blockchain reinventing energy grids?

Forbes, 5 companies spearheading blockchain for renewable energy, 2019

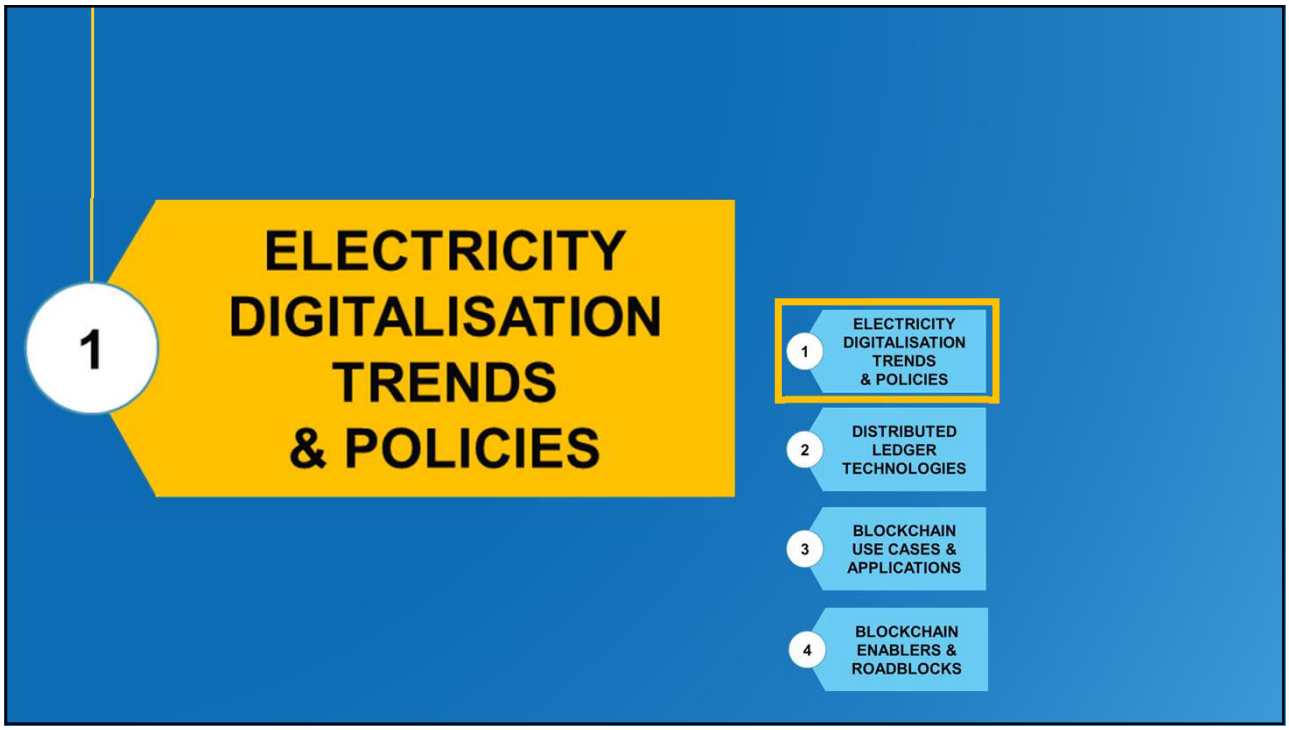
4

Forbes, 5 companies spearheading blockchain for renewable energy, 2019

4


What we will talk about
1
ELECTRICITY DIGITALISATION TRENDS & POLICIES
2
DISTRIBUTED LEDGER TECHNOLOGIES
3
BLOCKCHAIN USE CASES & APPLICATIONS
4
BLOCKCHAIN ENABLERS & ROADBLOCKS
3.a
POWER SYSTEM BLOCKCHAIN SOLUTIONS
3.b
ENERGY SYSTEM BLOCKCHAIN SOLUTIONS
3.c
INTEGRATED BLOCKCHAIN SOLUTIONS
5

5

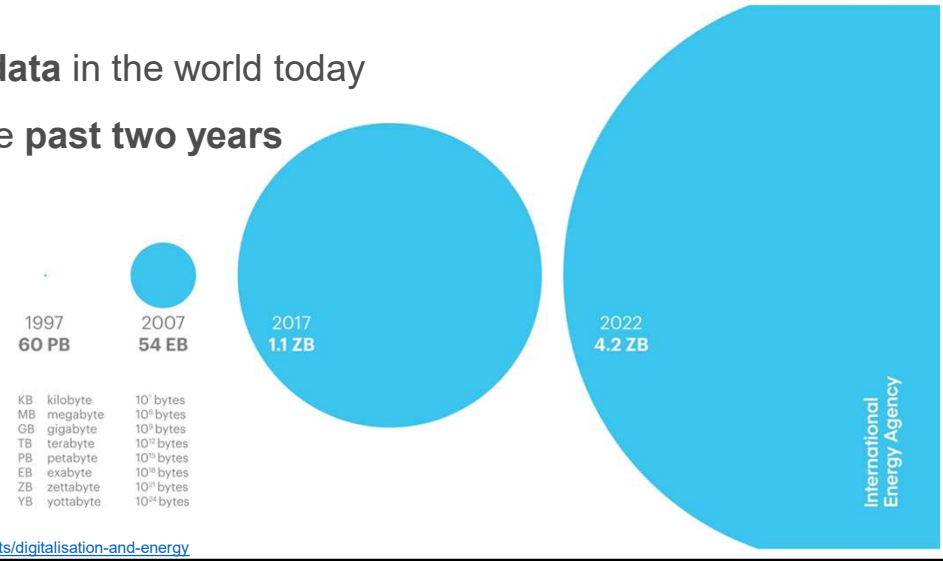

1
ELECTRICITY DIGITALISATION TRENDS & POLICIES
1
ELECTRICITY DIGITALISATION TRENDS & POLICIES
2
DISTRIBUTED LEDGER TECHNOLOGIES
3
BLOCKCHAIN USE CASES & APPLICATIONS
4
BLOCKCHAIN ENABLERS & ROADBLOCKS

6

1st exponential trend: global internet traffic

90% of the data in the world today

created in the **past two years**



7

https://www.iea.org/reports/digitalisation-and-energy

7

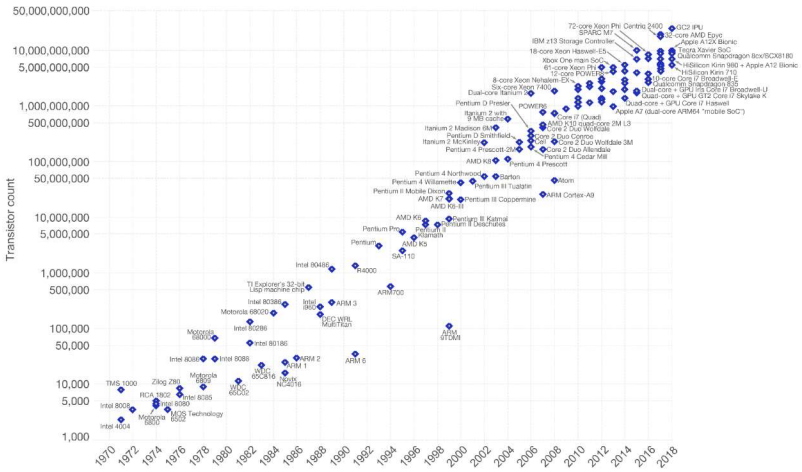
2nd exponential trend: Moore's "law"

processing power

(transistor number on

a microchip) **doubles**

every 2 years



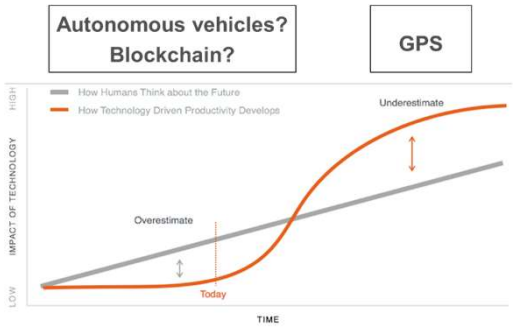
8

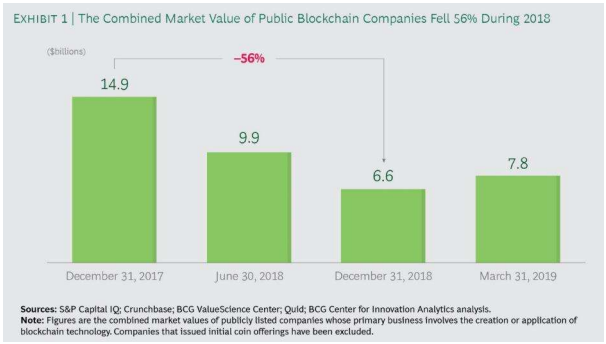
https://en.wikipedia.org/wiki/Moore%27s_law

8

…Amara's "law"

overestimate in the short run - underestimate in the long run





9 BCG, Decoding the Slowdown in Blockchain Startups, 2019
https://www.bresslergroup.com/blog/design-defined-how-does-amaras-law-inform-design-strategy/
https://en.wikipedia.org/wiki/Roy_Amara

9

Three digital transformation challenges

- Who **owns** (machine-made) **data**?
- "**Platform**isation" of economy
- Cyber **security**

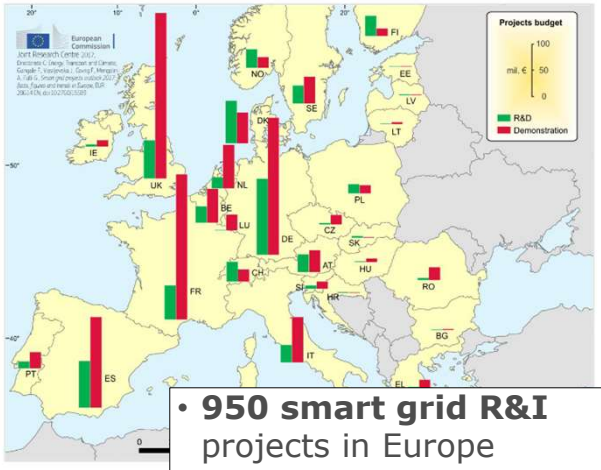
300 Digital Innovation Hubs across Europe

10 JRC digital transformation in energy and other sectors, 2019
https://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool

10

Digitalisation as energy transition enabler

- **Whole energy** value **chain** impacted
- **New functions**, **technologies** and **infrastructures**
- Free flows of power **and** data

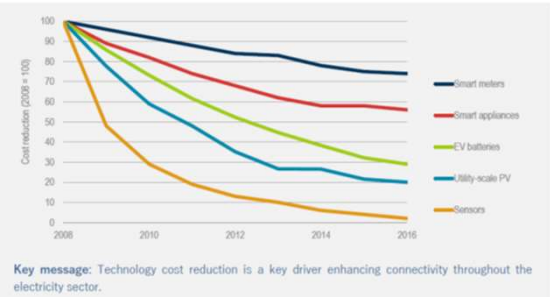


- **950 smart grid R&I** projects in Europe
- **5 billion EUR** invested

11 https://ec.europa.eu/energy/topics/technology-and-innovation/digitalisation_en
JRC Digital transformation in energy and other sectors, 2019
JRC Smart Grid Projects Outlook. 2017

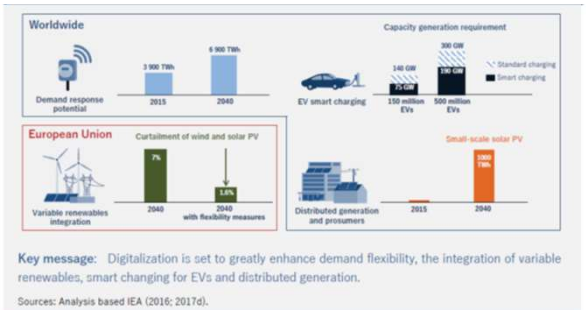
Energy & digital technology changes

Unit costs of key emerging technologies



Key message: Technology cost reduction is a key driver enhancing connectivity throughout the electricity sector.

Four elements for a digital electricity system



Key message: Digitalization is set to greatly enhance demand flexibility, the integration of variable renewables, smart charging for EVs and distributed generation.

Sources: Analysis based IEA (2016; 2017d).

12 IEA, Digitalization and energy, 2017

Electricity digitalisation

More **ICT, sensors, electronics & data analytics** can **improve:**

- **Electricity system** performances
- **Connectivity** within and **beyond the power system** between humans, devices and machines

bettering → system operation & maintenance and efficiencies

fostering → customer involvement and sector coupling (also with smart cities & communities)

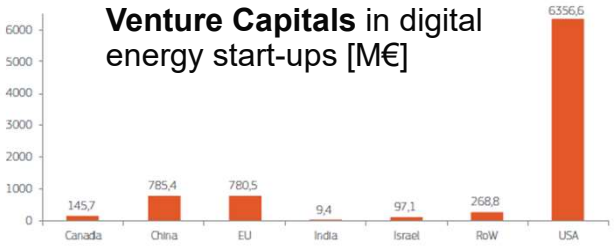
13 IEA, Digitalization and energy, 2017
ETIP SNET, Digitalization of the energy system and customer participation, 2018

13

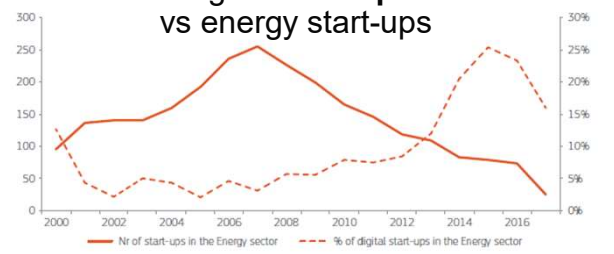
Digital/energy investments

Global investment in digital electricity infrastructure & software: **USD 47 billion in 2016** (growing by 20% annually in the past few years)

Venture Capitals in digital energy start-ups [M€]



Digital **start-ups** vs energy start-ups



14 IEA, Digitalization and energy, 2017
JRC, Digital transformation in energy and other sectors, 2019

14

Quiz/poll for you

What are among the main components of power system digitalisation?

A. Data, analytics & connectivity, electronics

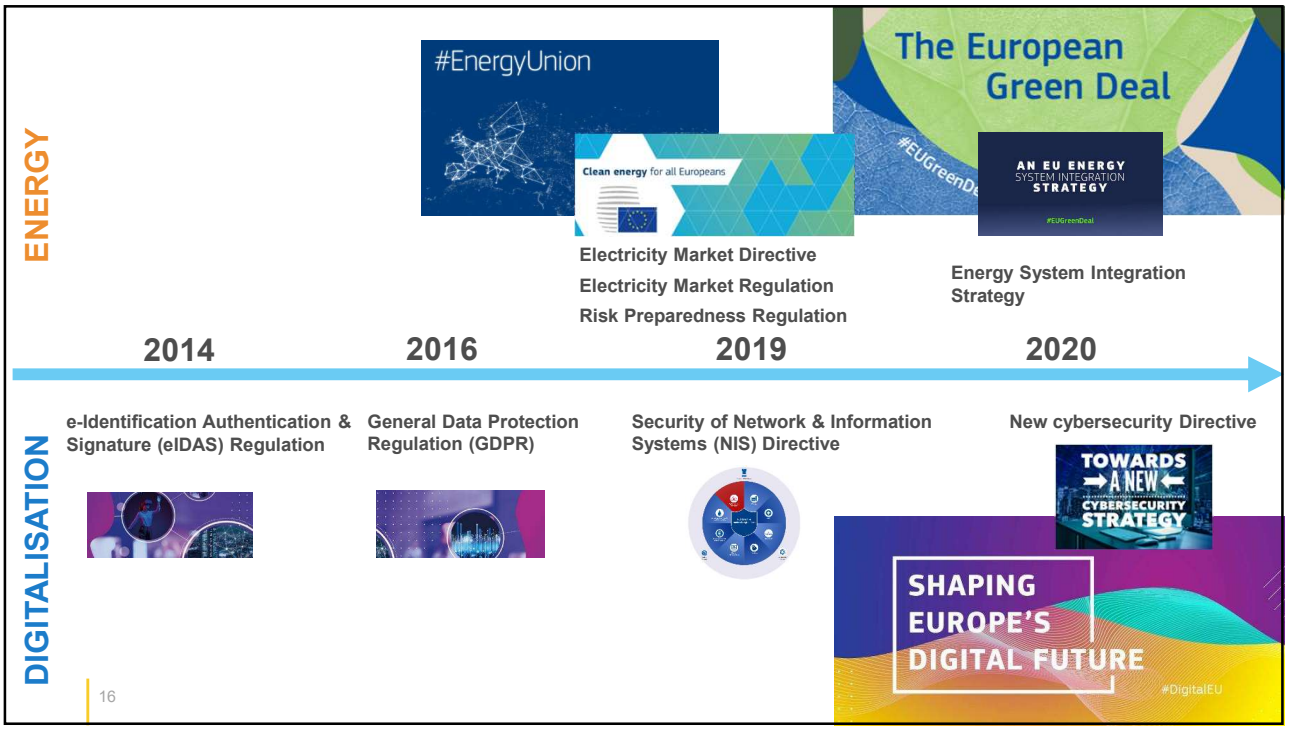
B. Data, analytics & investments, underground cables

C. Overhead lines, planning, maintenance & connectivity

D. Overhead lines, data & analytics, electronics

15

15



16

EU's twin green and digital ambitions

- European energy market: fully integrated, interconnected and **digitalised**
- **Digital** technologies **enabler** for sustainability but also big **energy consumers**
- Accessible and **interoperable data** are at the heart of **innovation**

17 European Commission, Communication COM(2019) 640 final, The European Green Deal
European Commission, Communication, Shaping Europe's digital future, 2020

17

2014-16 Digital ID & Data Protection Regulations

2014 **e-Identification Authentication & Signature (eIDAS)** Reg.:

- Use of national electronic identification schemes (eIDs) to access public services in other EU countries
- European internal market for electronic trust services (e-signatures, web authentication,…)

2016 **General Data Protection Regulation (GDPR)**

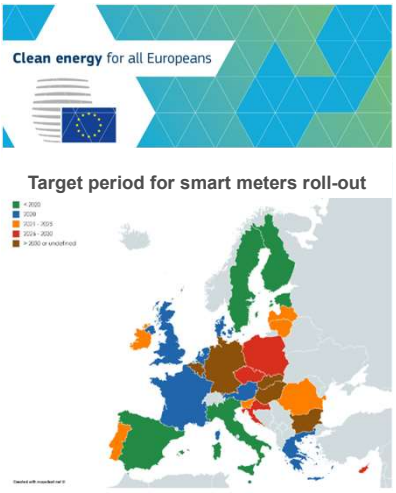
- Protection of personal data processing and free data movement
- Clarifying rules for companies and public bodies in the digital single market

18 EU Electronic Identification Authentication and Signature (eIDAS) Regulation 910/2014
EU General Data Protection Regulation (GDPR) Regulation 2016/679

18

2019 Electricity Directive

- **Smart metering** systems: **266 million smart meters** (**€46 billion**) in the EU **by 2030**
- **Data** management and **interoperability**
- **Distribution** system operators as neutral **market facilitator** and flexibility services provider
- **Digitalisation** among the tasks of the **Transmission** system operator



19 Electricity market Directive (EU) 2019/944
EC Tractebel, Smart metering benchmarking report, 2019

19

2019 Electricity Regulation

- **Digitalisation investments** for flexibility services
- Network **charges** to support (also) **digitalisation** innovation
- **Transmission / distribution** operators: **digitalisation** tasks, promotion of **cyber security** and **data protection / management**
- Network codes and rules for **cyber security** of **cross-border** electricity flows

20 Electricity market Regulation (EU) 2019/943

20

2019 Risk Preparedness Regulation

- Local electricity **crises** can rapidly **spread across borders**
- Some extreme events, such as cold spells, heat waves or **cyberattacks**, may affect entire regions at the same time
- **Cyber-incidents** identified as a **risk**, and the measures to address them reflected in the risk-preparedness plans

21

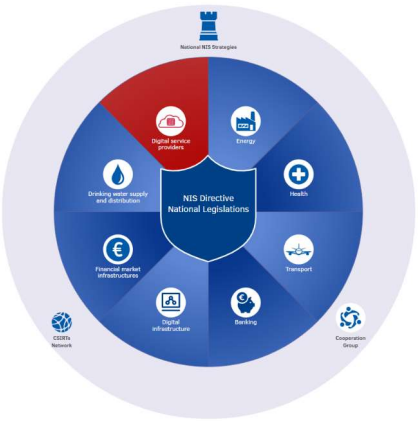
Risk Preparedness Regulation (EU) 2019/941

21

2021 Cybersecurity Directive

2020 Directive proposal to replace 2016 **Security of Network & Information Systems (NIS)** Directive:

- **resilience of emerging technologies** (e.g. 5G networks, AI, IoT, blockchain)
- **new sectors** (e.g. space) included
- no distinction between **operators of essential services** & **digital service providers**
- **strengthened** roles of **national** authorities and **Cooperation** Group

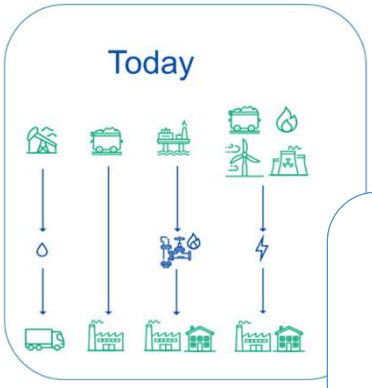


NIS Directive security of network and information systems 2016/944
EC Directive proposal high common level cybersecurity 2020
https://ec.europa.eu/digital-single-market/en/directive-security-network-and-information-systems-nis
https://ec.europa.eu/digital-single-market/en/cybersecurity-strategy
https://www.enisa.europa.eu/topics/nis-directive/nis-visualtool

22

22

Energy System Integration



Key Digitalisation actions:

- Energy Action plan
- Cybersecurity Network Code
- Data interoperability & access

23

EU Strategy for Energy System Integration COM(2020) 299 final

Quiz/poll for you

What are three main EU legislative acts addressing electricity digitalisation aspects?

A. European Union Blockchain Observatory & Forum, Electricity Regulation, Security of Network and Information Systems Directive
B. Electricity Directive, Electricity Regulation, European Blockchain Partnership
C. Electricity Directive, European Blockchain Partnership, Security of Network and Information Systems Directive
D. Electricity Directive, Electricity Regulation, Security of Network and Information Systems Directive

24

1 ELECTRICITY DIGITALISATION TRENDS & POLICIES

To learn more (1/2)

- https://ec.europa.eu/info/strategy/recovery-plan-europe_en
- https://ec.europa.eu/digital-single-market/en/content/european-digital-strategy
- https://ec.europa.eu/digital-single-market/en/directive-security-network-and-information-systems-nis-directive
- https://www.enisa.europa.eu/topics/nis-directive/nis-visualtool
- https://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool
- European Commission, Blockchain technologies
- European Blockchain Partnership (EBP)
- European Blockchain Services Infrastructure (EBSI)
- International Association of Trusted Blockchain Applications (INATBA)
- European Union Blockchain Observatory & Forum
- EU Electronic Identification Authentication and Signature (eIDAS) Regulation 910/2014
- Mourshed et al., Smart Grid Futures, 2015
- Accenture, Digital Disruption: the Growth Multiplier, 2016
- EU NIS Directive security of network and information systems 2016/944
- EU General Data Protection Regulation (GDPR) Regulation 2016/679
- IEA, Digitalization and energy, 2017
- JRC, Smart Grid Projects Outlook, 2017

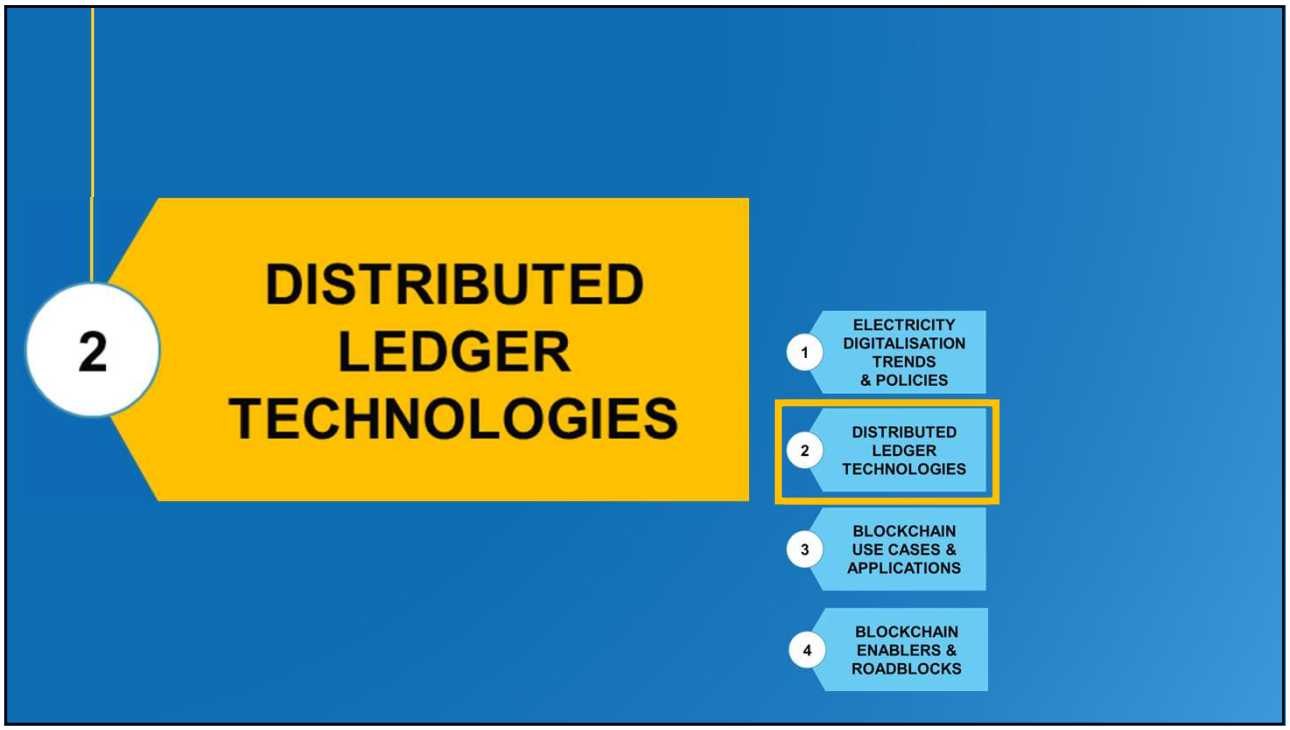
25

1 ELECTRICITY DIGITALISATION TRENDS & POLICIES

To learn more (2/2)

- EU Regulation 2018/1807 Free flow of non-personal data
- JRC, Distribution System Operators Observatory, 2018
- ETIP SNET, Digitalization of the energy system and customer participation, 2018
- IRENA, Innovation landscape for a renewable-powered future, 2019
- JRC, Digital transformation in energy and other sectors, 2019
- EC Tractebel, Smart metering benchmarking report, 2019
- Andoni et al., Blockchain energy systematic review, 2019
- Forbes, 5 companies spearheading blockchain for renewable energy, 2019
- Electricity market Directive (EU) 2019/944
- Electricity market Regulation (EU) 2019/943
- Risk Preparedness Regulation (EU) 2019/941
- European Commission, Communication COM(2019) 640 final, The European Green Deal
- European Commission, Communication, Shaping Europe's digital future, 2020
- EC, Regulation proposal crypto-assets markets, 2020
- EC Directive proposal high common level cybersecurity 2020
- OECD, Digital Economy Outlook, 2020
- EU Strategy for Energy System Integration COM(2020) 299 final

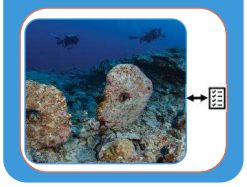
26



27

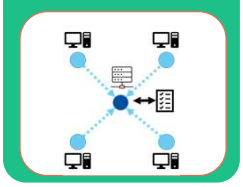
Ledger = database of records

ORAL/PAPER LEDGER



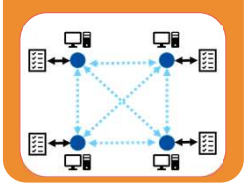
Records updated over time via a **centralised (oral, paper) medium**

DIGITAL LEDGER



Records updated on a **centralised digital system** (i.e. a server) and just replicated in **different locations**

DISTRIBUTED LEDGER TECHNOLOGIES



Records actively **updated** and **maintained in different locations** via a **decentralised**, peer-to-peer network of nodes (no central server)

BLOCKCHAIN

bitcoin ethereum

DIRECT ACYCLIC GRAPH (DAG)

IOTA

HASHGRAPH

Swirlds

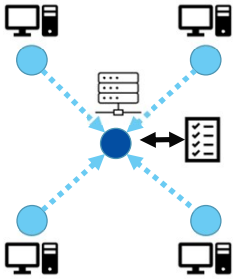
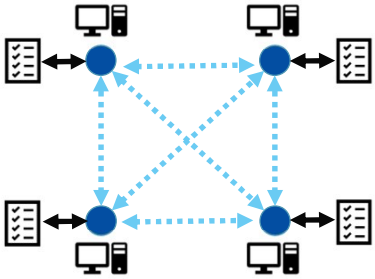
OTHER…

HOLOCHAIN

28 Belotti et al., Vademecum blockchain 2019
https://www.sciencealert.com/the-original-bitcoin-still-exists-as-giant-stone-money-on-a-tiny-pacific-island

28

Centralised vs. distributed transactions

	CENTRALISED	DISTRIBUTED
		
• Parties with no mutual trust can exchange data	• Via a central **intermediary**	• On a peer-to-peer basis **without intermediaries**
• The system transactions can be accessed and verified by	• A few (one)	• Many (all)
• The ledger is maintained (records are validated) by	• The intermediary via a **centralised validation** process	• The network members via a **distributed consensus** process

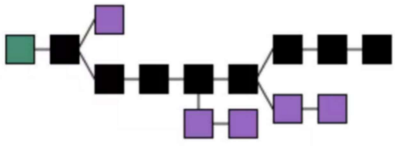
29 JRC, Blockchain now and tomorrow, 2019
Andoni et al., Blockchain energy systematic review, 2019

29

Different Distributed Ledger Technologies

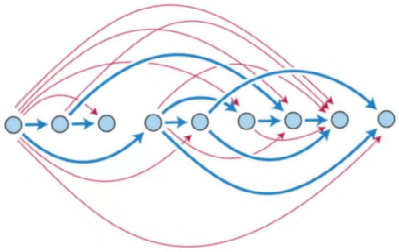
BLOCKCHAIN

bitcoin ethereum



DIRECT ACYCLIC GRAPH (DAG)

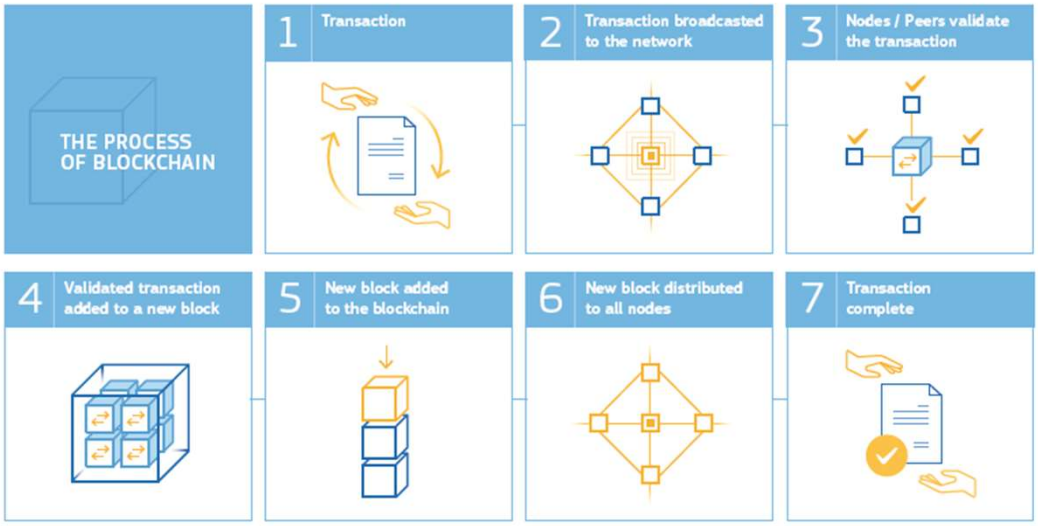
IOTA



30 https://medium.com/@kotsbtechcdac/dag-will-overcome-blockchain-problems-dag-vs-blockchain-9ca302651122
Salek Ali et al., Applications blockchains IoT review, 2019

30

How a blockchain works

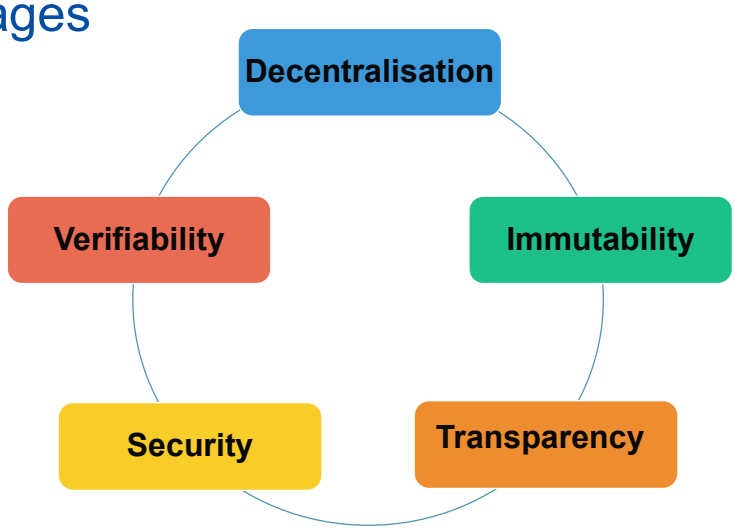


31

JRC, Blockchain now and tomorrow, 2019

31

Key blockchain advantages

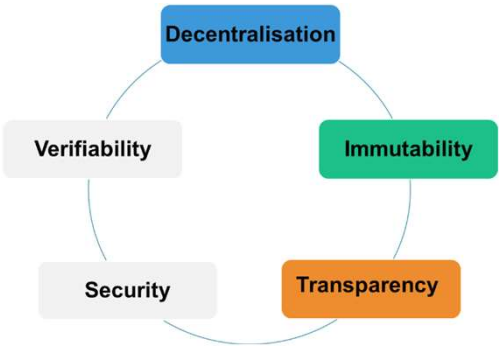


32

United Nations Development Program, The future is decentralized, 2018
Energy Web Foundation, OECD digital security workshop, 2018
JRC, Blockchain now and tomorrow, 2019

32

More on the key blockchain advantages

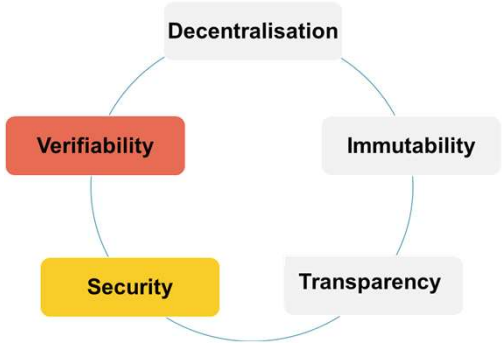


- **Decentralisation**: A blockchain is run through a distributed network of participants who do not necessarily trust each other
- **Immutability** (or better, tamper resistance): It is extremely difficult to change or delete the record of transactions
- **Transparency**: Transactions are visible to all (or a predefined set of) participants

33

33

More on the key blockchain advantages

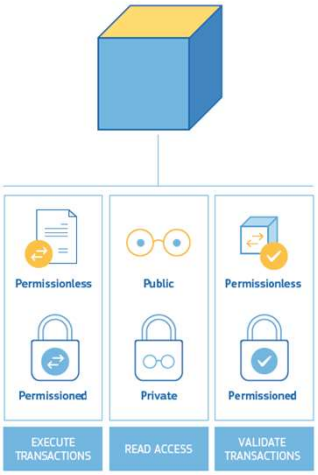


- **Security**: All transactions are protected by cryptography, time-stamped and there is no single point of failure
- **Verifiability**: As a combination of transparency and immutability anyone can check that the rules are being followed

34

34

Public/private blockchains & permissions



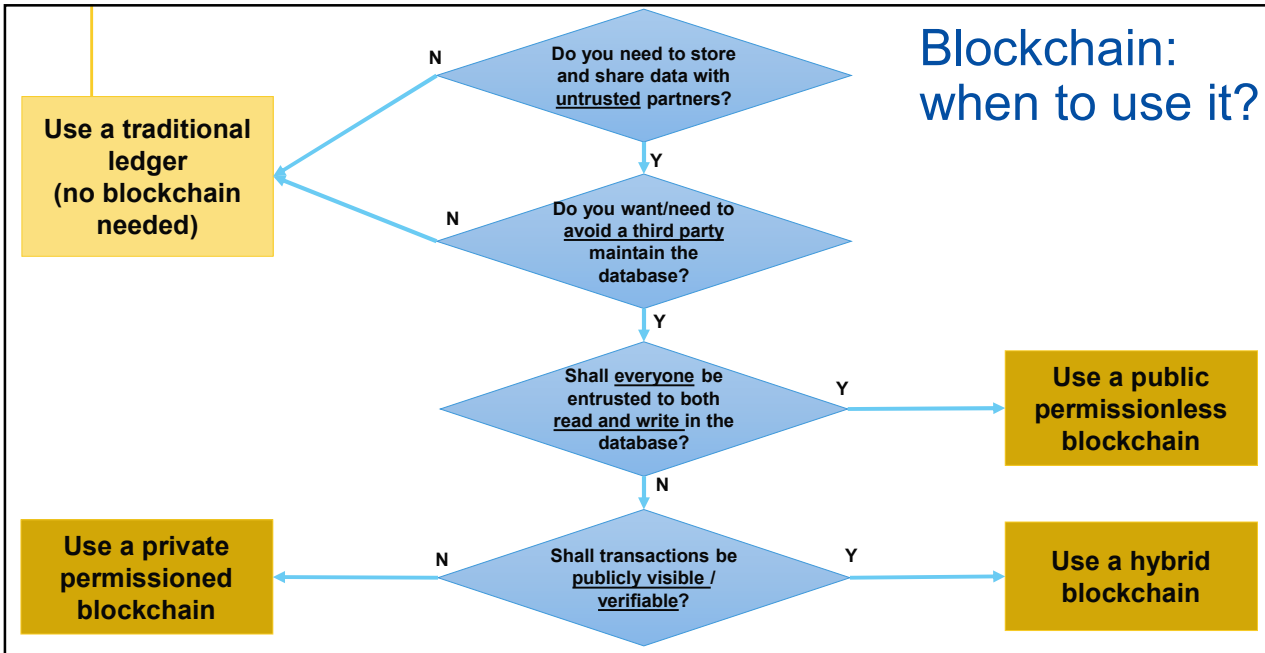
Blockchain type	Explanation	Example	Visualisation
Public permissionless blockchains	In these blockchain systems, everyone can participate in the blockchain's consensus mechanism. Also, everyone worldwide with an internet connection can transact and see the full transaction log.	Bitcoin, Litecoin, Ethereum	
Public permissioned blockchains	These blockchain systems allow everyone with an internet connection to transact and see the blockchain's transaction log, although only a restricted number of nodes can participate in the consensus mechanism.	Ripple, private versions of Ethereum	
Private permissioned blockchains	These blockchain systems restrict both the ability to transact and view the transaction log to only the participating nodes in the system, and the architect or owner of the blockchain system is able to determine who can participate in the blockchain system and which nodes can participate in the consensus mechanism.	Rubix, Hyperledger	
Private permissionless blockchains	These blockchain systems are restricted in who can transact and see the transaction log, although the consensus mechanism is open to anyone.	(Partially) Exonum	

35

JRC, Blockchain now and tomorrow, 2019

35

Blockchain: when to use it?

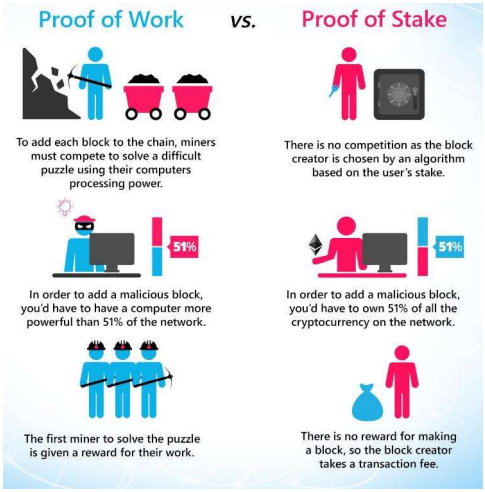


36

Adapted from European Parliament, Blockchain for supply chains and international trade, 2020
Adapted from Belotti et al., Vademecum blockchain 2019

36

Lottery-based consensus algorithms

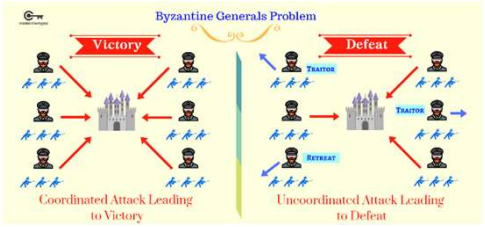


- Lottery-based consensus algorithms:
  - **Proof of Work** (PoW) used by Bitcoin
  - **Proof of Stake** (PoS) now used by Ethereum
  - Proof of Elapsed Time (PoET), used by Hyperledger Sawtooth
- The **winner** of the **lottery proposes** a block and transmits it to the rest of the network for validation
- They handle **large number of nodes** but may be **slower in finalising** transactions (if two "winners" propose a block, each fork must be resolved)

37 Hyperledger Architecture Volume 1
https://blockgeeks.com/wp-content/uploads/2019/05/proofofworkvsproofofstake-1.jpg

37

Voting-based consensus algorithms



- Voting-based consensus algorithms:
  - **Practical Byzantine Fault Tolerance (PBFT),** adopted by Hyperledger Fabric
  - Consortium PBFT,…
- When a **majority** of nodes validates (i.e. **votes** for) a transaction/block, consensus exists and finality occurs
- **Trade-off** between **scalability** and latency: the algorithm is **quicker** but the more nodes are on the net, the more time it takes to reach consensus

38 Hyperledger Architecture Volume 1
https://masterthecrypto.com/guide-to-consensus-algorithms-what-is-consensus-mechanism/
Lamport et al., Byzantine generals problem, 1982

38

Quiz/poll for you

What are three main advantages of blockchain technologies?

A. Energy saving, Transparency, Security

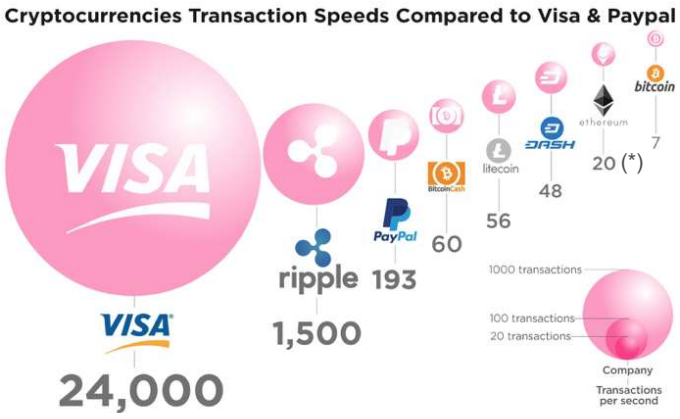
B. Immutability (tamper resistance), Transparency, Security

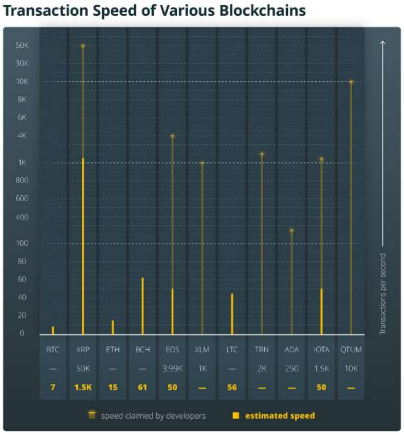
C. Technological maturity, Transparency, Security

D. Energy saving, Transparency, Liability

39

Blockchain transaction speed (throughput)





(*) Ethereum 2.0 claims to deliver 100,000 tps

40

https://medium.com/@s_o_s/blockchain-and-transaction-speed-why-does-it-matter-80bfd100fa89
https://cointelegraph.com/news/who-scales-it-best-inside-blockchains-ongoing-transactions-per-second-race

CONSENSUS MECHANISMS COMPARISON	Proof of Work	Proof of Stake	Proof of Elapsed Time	Practical Byzantine Fault Tolerance & variants	Consortium Practical Byzantine Fault Tolerance
Acronym	PoW	PoS	PoET	PBFT & variants	Consortium PBFT
Node identity management	permissionless	permissionless or permissioned	permissionless or permissioned	permissioned	permissioned
Lottery based or voting based	lottery based	lottery based	lottery based	voting based	voting based
Energy saving	No	partial	partial	yes	yes
Tolerated power of the adversary	< 51% power	< 51% power	Trusted Execution Environment (TEE)	< 33.3 % replicas	Variable (< 20% - 33.3 %)
Finality	no	no	no	yes	yes
Transaction finality	probabilistic	probabilistic	probabilistic	immediate	immediate
Transaction rate	low	high	medium	high	high
Token needed and cost of participation?	yes	yes	no	no	no
Nodes scalability	good (> 1000)	good (> 1000)	good (> 1000)	moderate (< 100)	moderate (100 – 1000)
Throughput (tps)	7-30	100-200	1000	up to 110K	up to 10K
Speed	poor	poor	N.A.	good	good
Trust model	untrusted	untrusted	untrusted	semi-trusted	semi-trusted

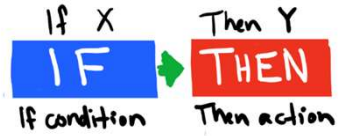
41 Belotti et al., Vademecum blockchain 2019
Panarello et al., Blockchain IoT integration, 2018
Hyperledger Architecture Volume 1

41

Smart contracts

> "Smart contracts are neither 'smart' (capable of translating complex legal agreements) *nor 'contracts' (no underlying legal provisions).*"

- Smart contracts are **computer programs carrying out** the terms of **agreements** between parties without the need for human intervention
- They are recorded and validated in a blockchain (such as **Ethereum, Hyperledger**) which can automatically execute and enforce the contract usually under '**if-then**' instructions

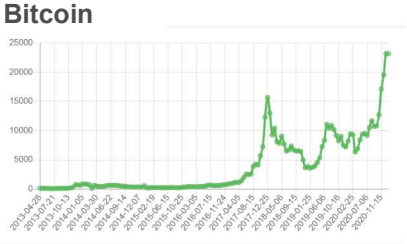


42 JRC, Blockchain now and tomorrow, 2019

42

Bitcoin vs Ethereum

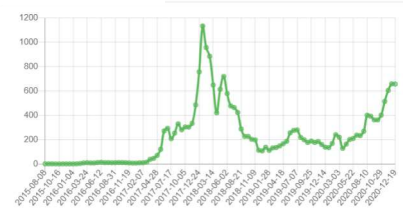
Bitcoin



PROs
- No financial intermediaries, **low transaction costs**
- **Secure** system for storing or timestamping a document

CONs
- High **volatility** currency, mostly used as a speculative asset
- Proof of Work limits: transaction **speed** and **latency**, size of the blockchain and **energy consumption**
- only limited smart contracts

Ether



PROs
- Complex **smart contracts** and decentralised apps
- Transition to Ethereum 2.0 - Proof of Stake with sharding(each node has only part of the data), boosting transaction **speed**

CONs
- High **volatility** currency
- **Security** of smart contracts

43 European Parliament, Blockchain for supply chains and international trade, 2020
https://walletinvestor.com/compare/bitcoin-vs-ethereum/interval/all

43

BITCOIN-ETHEREUM-HYPERLEDER COMPARISON	Bitcoin	Ethereum	Hyperledger (Hyperledger Fabric, Hyperledger Sawtooth,…)
Usage level	Very High	High	Emerging
Description	Public blockchain used as a support for a cryptocurrency	Public blockchain-based platform designed to run smart contracts	Modular architecture allowing - components to be plug-and-play (Fabric) - for building, deploying and running distributed ledgers (Sawtooth)
Main value proposition	Alternative to traditional centralised banking systems	Platform for the creation of advanced smart contracts	- Toolkit to create custom B2B blockchains (Fabric) - Industry solution to create public or permissioned blockchains with an alternative to Proof of Work (Sawtooth)
Governance	None (Bitcoin community)	None (Ethereum community)	Linux Foundation
Institutional player support	None	None	IBM, Intel
Public or permissioned	Public	Public	Public or permissioned
Cryptocurrency or token	Bitcoin (BTC) cryptocurrency	Ether (ETH) cryptocurrency and tokens via smart contracts	No (Fabric) Cryptocurrency/token optional (Sawtooth)
Smart contract availability (and language)	Limited (non Turing-complete)	Advanced (non Turing-complete)	Advanced (support a variety of languages) – smart contracts are also named chaincodes
Consensus algorithm	Proof of Work - PoW	Recently moved to Proof of Stake - PoS (previously Proof of Work)	Practical Byzantine Fault Tolerance and various others (Fabric) Proof of Elapsed Time - PoET (Sawtooth)
Throughput (tps – transactions per second)	7 tps	15-40 tps; 100 thousand tps (Ethereum 2.0)	dozen of thousands tps
Latency (second)	600 s	~ 15 s	< 1 s

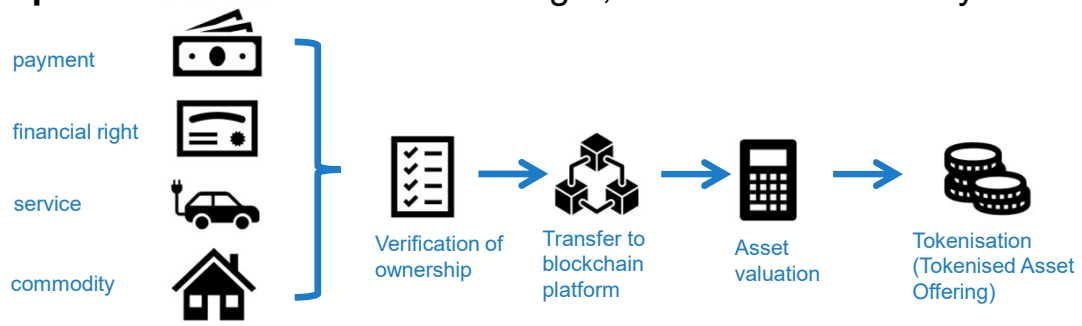
44 European Parliament, Blockchain for supply chains and international trade, 2020
Belotti et al., Vademecum blockchain 2019

44

The tokenisation potential

Digital **tokens**: medium (associated with a blockchain) to register:

- exchanges/transactions (means of **payment**)
- a **promise** to deliver a financial right, service or commodity



45

JRC, Blockchain now and tomorrow, 2019

45

Blockchain market

- The **blockchain technology in energy** market is predicted to hike from USD 200 million in 2018 to **USD 18 billion by 2025**
- Exponential growth in fund-raising via **Initial Coin Offerings (ICOs)** but start-ups **survival rate after 120 days** is only **44.2%**

2016		2017		2018	
Company	Amount raised (USD million)	Company	Amount raised (USD million)	Company	Amount raised (USD million)
Waves	16.4	Hdac	258.0	EOS	4198.0
Iconomi	10.6	Filecoin	257.0	Telegram ICO	1700.0
Golem	1196.0	Tezos	1196.0	Ruby-X	1196.0
SingularDTV	7.5	Sirin Labs	157.9	Petro	735.0
Lisk	5.7	Bancor	153.0	TaTaTu	575.0
Digix DAO	5.5	Polkadot	144.6	Dragon	420.0
FirstBlood	5.5	Qash	107.3	Huobi token	300.0
Synereo	4.7	KIK	98.5	Bankera	150.9
Decent	4.2	COMSA	95.4	Neluns	136.0
Antshares/ NEO	3.6	Status	90.0	tZERO (STO)	134.0

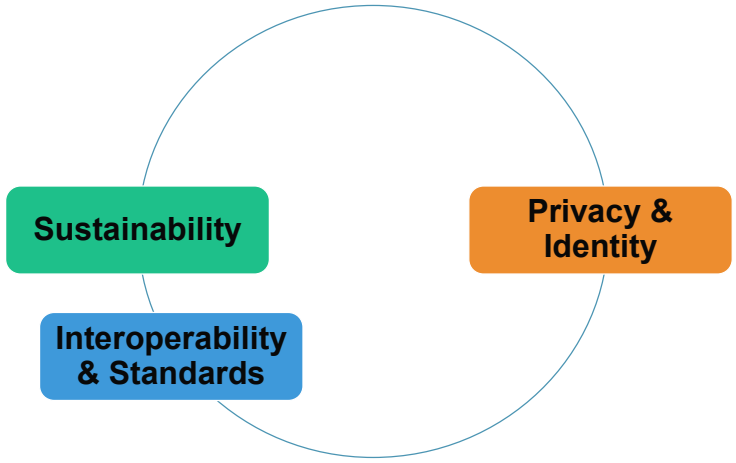
Table 3: Top 10 ICOs by amount raised, per year and at the ICO closing date. Amounts are valued using the BTC exchange rate at that time (as of 13 November 2018)
Source: www.coinschedule.com

Global Market Insights, Blockchain in Energy Market, 2019
OECD, Digital Economy Outlook, 2020
JRC, Blockchain now and tomorrow, 2019
Benedetti et al., Digital tulips return investors ICOs, 2018

46

46

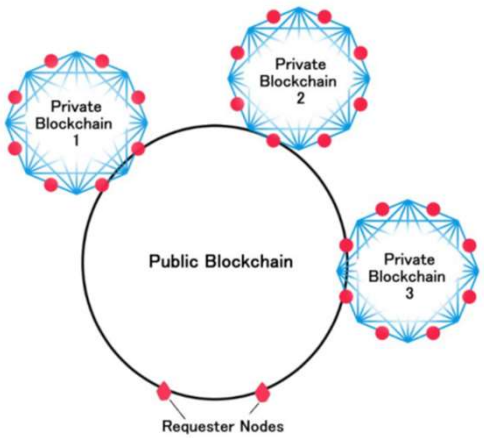
Some blockchain challenges



47

47

Privacy solutions: private-public blockchains



A promising solution for private-by-design IoT data transfer is using a **multi-layer architecture** for blockchains

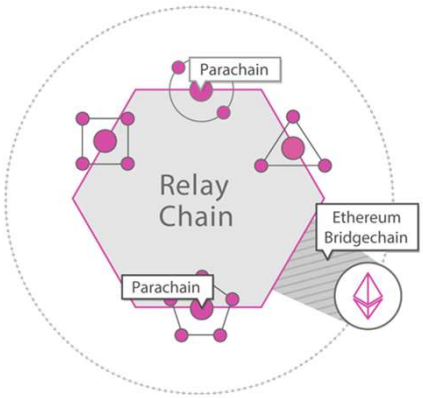
- Multiple **private blockchains connect to a public** blockchains
- Users in separate private blockchains can choose to **selectively communicate data** to other blockchains

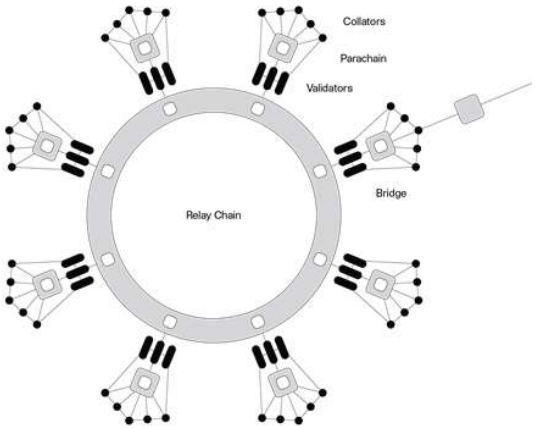
48

Salek Ali et al., Applications blockchains IoT review, 2019

48

Interoperability issues: the Polkadot solution



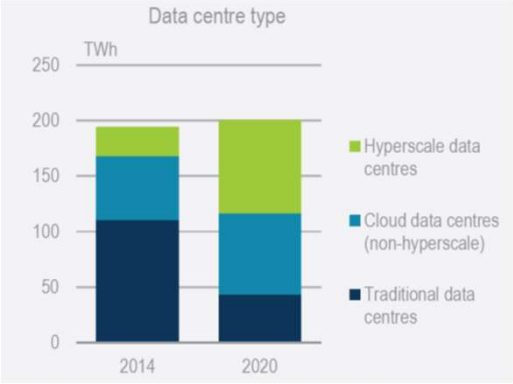


49 https://medium.com/coinmonks/polkadot-series-part-1-overview-1ad0c7b8d442
https://www.parity.io/a-brief-summary-of-everything-substrate-polkadot/

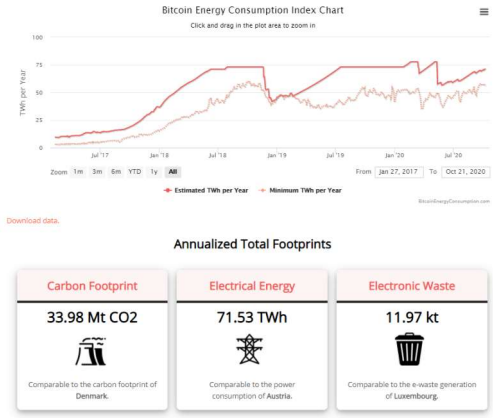
49

The sustainability/energy efficiency issue

Data centres annual energy consumption = Belgium+Netherlands (**~200 TWh**)



Bitcoin annual energy consumption? = Austria (**~70 TWh**)

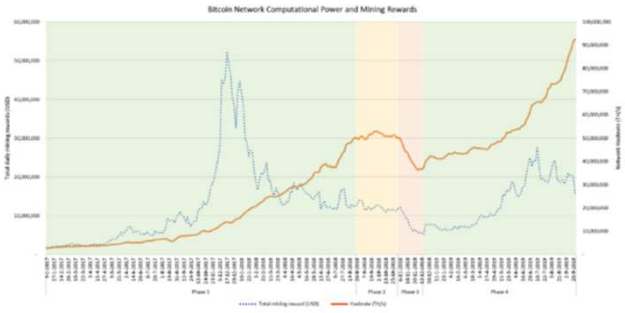


50 IEA, Digitalization and energy, 2017
Bitcoin Energy Consumption Index

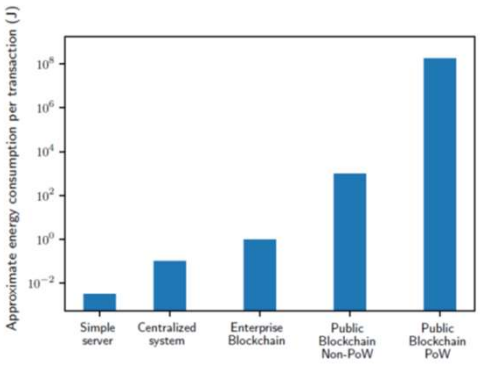
50

Blockchain energy consumption reassessed

Bitcoin annual **electricity consumption** re-assessed closer to Belgium (**~90 TWh)** (rather than Austria) when considering market dynamics and miners' behaviours



However **non-Bitcoin** and non-Proof of Work based blockchains display better energy performances



de Vries, Bitcoin consumption underestimated, 2020
de Vries, Bitcoin growing energy problem, 2018
Sedlmeier, The Energy Consumption of Blockchain Beyond Myth, 2020

51

51

Quiz/poll for you

What system can handle more transactions per second?

A. Visa, then Paypal, then Ethereum 1.0, then Bitcoin
B. Ethereum 1.0, then Visa, then Paypal, then Bitcoin
C. Bitcoin, then Ethereum 1.0, then Visa, then Paypal
D. Bitcoin, then Paypal, then Ethereum 1.0, then Visa

52

52

2 DISTRIBUTED LEDGER TECHNOLOGIES

To learn more (1/2)

- https://www.sciencealert.com/the-original-bitcoin-still-exists-as-giant-stone-money-on-a-tiny-pacific-island
- Bitcoin Energy Consumption Index
- Ethereum Energy Consumption Index
- https://bitcoin.org/en/
- https://eth.wiki/
- Hyperledger Architecture Volume 1
- https://txstreet.com/
- Lamport et al., Byzantine generals problem, 1982
- Nakamoto, Bitcoin: A Peer-to-Peer Electronic Cash System, 2008
- Buterin, Ethereum Whitepaper, 2013
- O'Dwyer et al., Bitcoin mining and its energy footprint, 2014
- Mourshed et al., Smart Grid Futures, 2015
- PwC, Blockchain - an opportunity for energy producers and consumers?, 2016
- IEA, Digitalization and energy, 2017

53

2 DISTRIBUTED LEDGER TECHNOLOGIES

To learn more (2/2)

- United Nations Development Program, The future is decentralized, 2018
- Panarello et al., blockchain IoT integration, 2018
- Wu et al., Application of blockchain sustainable energy, 2018
- de Vries, Bitcoin growing energy problem, 2018
- JRC, Blockchain now and tomorrow, 2019
- Andoni et al., Blockchain energy systematic review, 2019
- Belotti et al., Vademecum blockchain 2019
- Hassan et al., Blockchain technologies for smart energy systems, 2019
- EU Blockchain observatory and forum 2018-2020
- European Parliament, Blockchain for supply chains and international trade, 2020
- de Vries, Bitcoin consumption underestimated, 2020
- Sedlmeier, The Energy Consumption of Blockchain Beyond Myth, 2020
- EC Workshop: Data Driven Energy Services. How to Engage Consumers, 2020

54

3 BLOCKCHAIN USE CASES & APPLICATIONS

1 ELECTRICITY DIGITALISATION TRENDS & POLICIES

2 DISTRIBUTED LEDGER TECHNOLOGIES

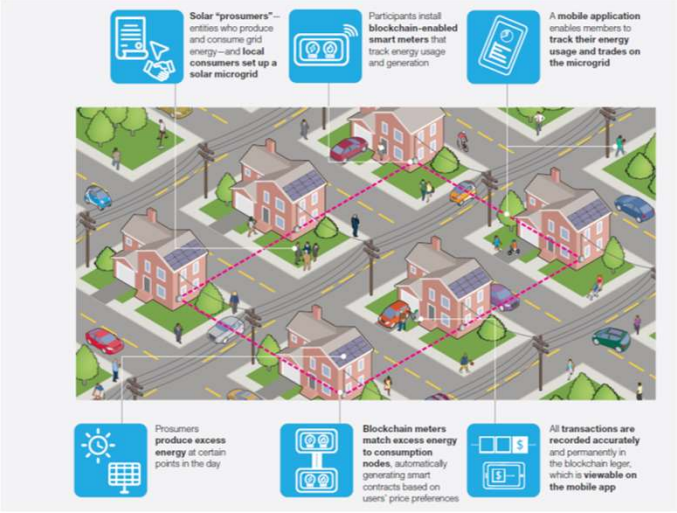
3 BLOCKCHAIN USE CASES & APPLICATIONS

- 3.a POWER SYSTEM BLOCKCHAIN SOLUTIONS
- 3.b ENERGY SYSTEM BLOCKCHAIN SOLUTIONS
- 3.c INTEGRATED BLOCKCHAIN SOLUTIONS

4 BLOCKCHAIN ENABLERS & ROADBLOCKS

55

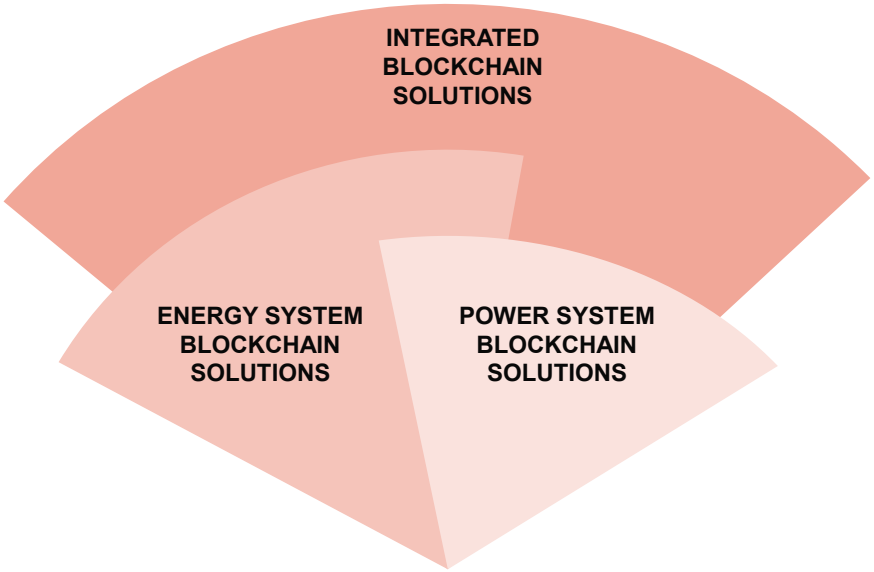
How blockchain can change the electricity business



56 McKinsey, What every utility CEO should know about blockchain, 2018
Andoni et al., Blockchain energy systematic review, 2019

56

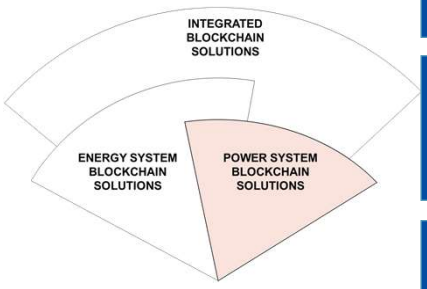
Use case classes in the electricity sector



57

57

Power system blockchain solutions



METERING & BILLING

Blockchains, smart contracts and smart metering can realise **automated** billing for consumers and distributed generators

ELECTRICITY MARKET & TRADING

Blockchain-enabled distributed trading platforms might **disrupt market** operations such as wholesale market management or commodity trading transactions

SYSTEM OPERATION & FLEXIBILITY

Blockchains could **assist in managing** decentralised networks, flexibility services or **power system** assets

ELECTRIC MOBILITY

The **decentralised** nature of electric **vehicles** and e-mobility makes them natural applications for blockchains

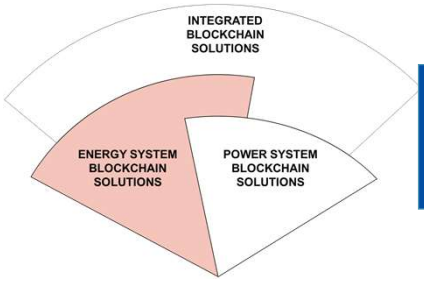
58

58

Energy system blockchain solutions

GREEN CERTIFICATES & CARBON CREDITS

Blockchain promises to **streamline** fragmented and complex **market** structures for renewable certificates, carbon credits or general environmental attributes



ENERGY CRYPTO-ASSETS & INVESTMENT

Cryptocurrencies are used as a method to '**tokenise**' energy assets, thus creating new markets or business models based on co-ownership and sharing

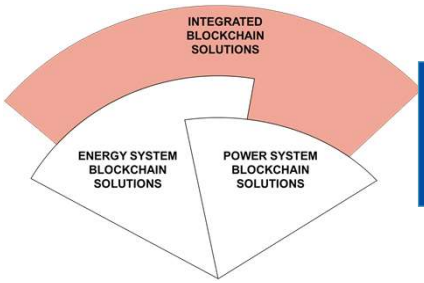
59

59

Integrated blockchain solutions

MULTI-PURPOSE & INTEGRATED PLATFORMS

Several governments, businesses and organisations established **collaborative** platforms to explore blockchain potential in a variety of use cases



INTERNET OF (ENERGY) THINGS

Blockchains could **enable IoT** platforms, smart devices communication and automation, facilitating machine-to-machine interactions and asset management

60

60

Quiz/poll for you

Which do you think are the most targeted use cases and deployed technologies in the power system domain?

A. Electric mobility charging transactions enabled by Bitcoin

B. Peer-to-peer electricity trading transactions enabled by Ethereum

C. Metering and billing transactions based on Iota

D. Emission/carbon credit transactions enabled by Hyperledger

61

61

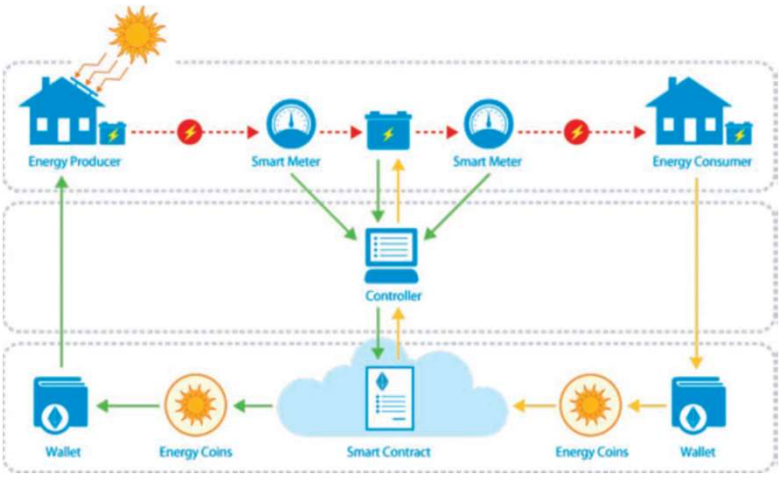
3.a POWER SYSTEM BLOCKCHAIN SOLUTIONS

METERING & BILLING	ELECTRICITY MARKET & TRADING	SYSTEM OPERATION & FLEXIBILITY	ELECTRIC MOBILITY
PROSUME • Bankymoon	Brooklyn microgrid • Enerchain • Power Ledger • KEPCO Osaka	Equigy • Hamburg Energie • Gridchain • Schoonschip • JRC DR test • Delta2020	Share & Charge • Everty

62

METERING & BILLING

INTRO



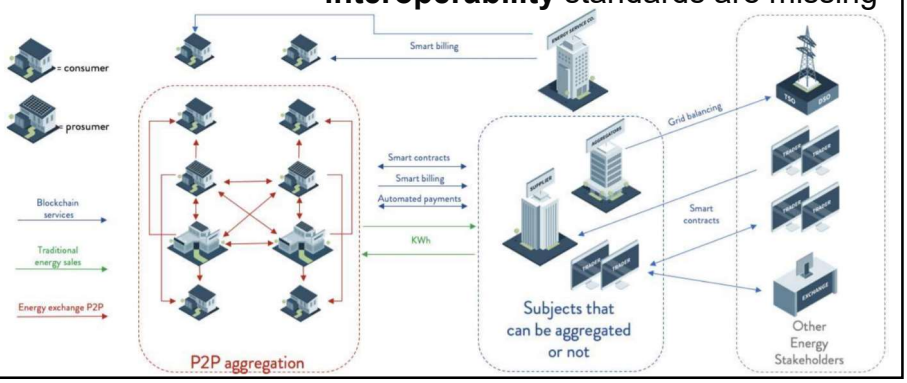
63 Andoni et al., Blockchain energy systematic review, 2019
JRC digital transformation in energy and other sectors, 2019

63

METERING & BILLING

PROSUME (Italy)

- **PROSUME: Real-time monitoring of prosumers' energy** consumption, production and expenditure
- Regular **payment** methods, with minimum delays and reduced costs
- Challenges: **smart meters** are **not blockchain-ready** and **interoperability** standards are missing



64 https://prosume.io/

64

METERING & BILLING

Bankymoon (South Africa

- **Bankymoon** integrates Bitcoin payments into smart meters
- Smart prepaid meters only release power when topped up with Bitcoins
- Challenges: bitcoin speed and **scalability**

"Imagine a student abroad who needs to have their meter topped up,"

"They'd phone their parent and ask them to send money."

"They can just go and top up the meter using bitcoin."

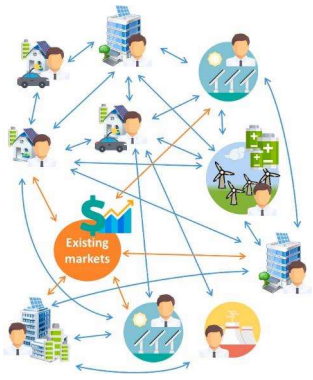
65 http://bankymoon.co.za/
Bankymoon Introduces Bitcoin Payments To Smart Meters For Power Grids
DENA, Burger et al., Blockchain in the Energy Transition Survey in the German Energy Industry, 2016

65

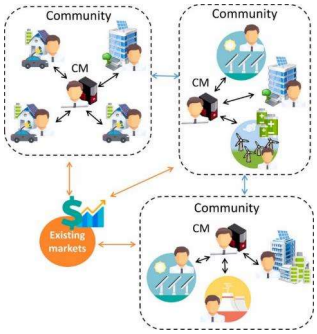
ELECTRICITY MARKET & TRADING

INTRO

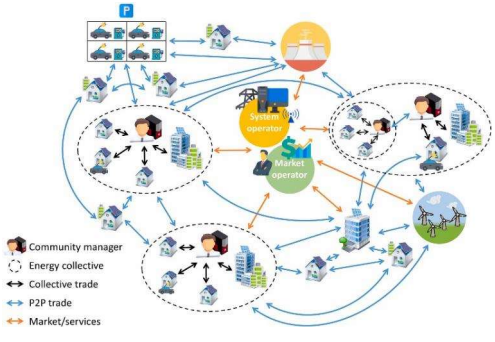
P2P Market design options



Full peer-to-peer



Community-based



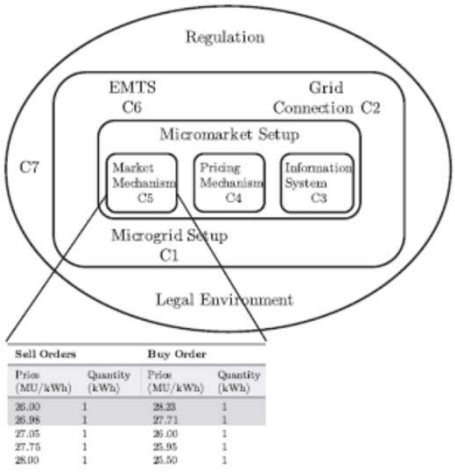
Hybrid peer-to-peer "Russian doll"

66 2019 Sousa, peer to peer and community based markets

66

ELECTRICITY MARKET & TRADING

Brooklyn microgrid (US)



Sell Orders		Buy Order	
Price (MU/kWh)	Quantity (kWh)	Price (MU/kWh)	Quantity (kWh)
26.00	1	28.23	1
26.98	1	27.71	1
27.05	1	26.00	1
27.75	1	25.95	1
28.00	1	25.50	1

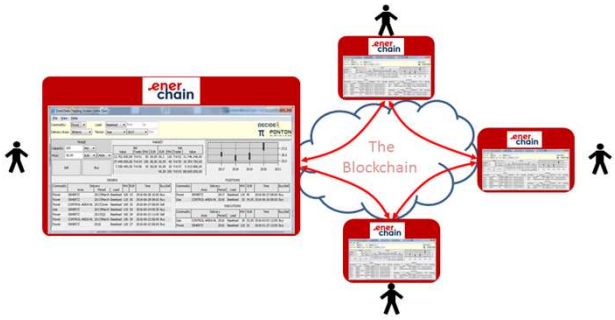
- **Brooklyn microgrid:** first blockchain-based P2P electricity market
- 2017 First pilot: local electricity trading without utility involvement **not covered by regulation** (3-month tests done with only 1 prosumer and 1 consumer)
- 2020: approval to conduct a 12-month pilot program (**regulatory sandbox**) for energy trading with 40 prosumers and 200 consumers

67 2019 Mengelkamp, designing microgrid markets: Brooklyn
https://www.brooklyn.energy/

67

ELECTRICITY MARKET & TRADING

Enerchain (Germany)



- **Enerchain/PONTON**: P2P local community, distribution flexibility and wholesale trading
- 2016: First energy trade demo in Europe by PONTON via Blockchain
- 2019: Enerchain released for live trading, after successful proof-of-concept with 44 European trading companies

PONTON
WE ARE THE 2 IN B2B

68 https://enerchain.ponton.de/index.php/16-gridchain-blockchain-based-process-integration-for-the-smart-grids-of-the-future
https://enerchain.ponton.de/index.php/articles
https://enerchain.ponton.de/

68

ELECTRICITY MARKET & TRADING

Power Ledger (Australia)

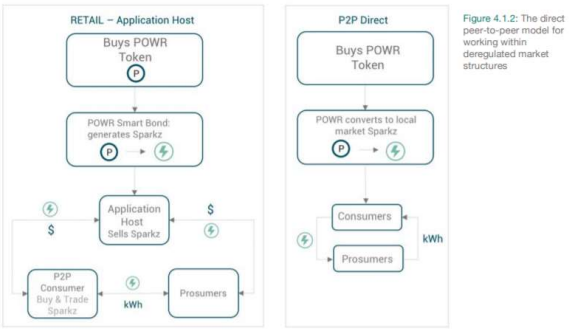
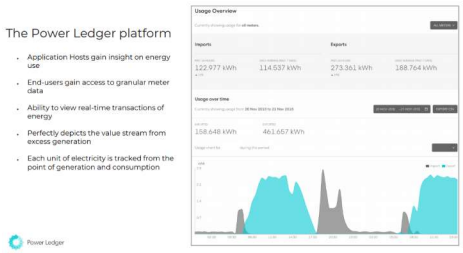


Figure 4.1.2: The direct peer-to-peer model for working within deregulated market structures

- **Power Ledger** platform based on Ethereum (**POWR** token) for energy trading with the aim of making energy markets more efficient
- The business helps people transact energy and renewables in local energy communities
- **Regulatory** frame still uncertain

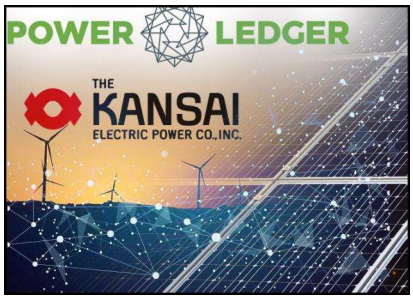


69 https://www.powerledger.io/
Power Ledger, Reimagining electricity market

69

ELECTRICITY MARKET & TRADING

KEPCO Osaka (Japan)



- Japanese utility **KEPCO** and **Power Ledger** trialed a blockchain-enabled demonstration in Osaka for surplus power **peer-to-peer trading** (replacing the feed-in tariffs regime)
- The trial showed how energy-generating customers can monetize their renewable energy investments by **selling their excess energy** via Power Ledger's P2P platform

70 Gonzalez, Blockchain in Japan, 2018
Power Ledger, KEPCO peer-to-peer energy trading results, 2019
EU Blockchain Observatory & Forum, Energy and Sustainability workshop, 2020

70

Quiz/poll for you

What is one the biggest hurdles in the deployment of blockchain-based electricity market & trading applications?

A. Scalability and lack of interest of trading companies

B. Lack of blockchain software solutions and regulatory framework

C. People acceptance and lack of interest of trading companies

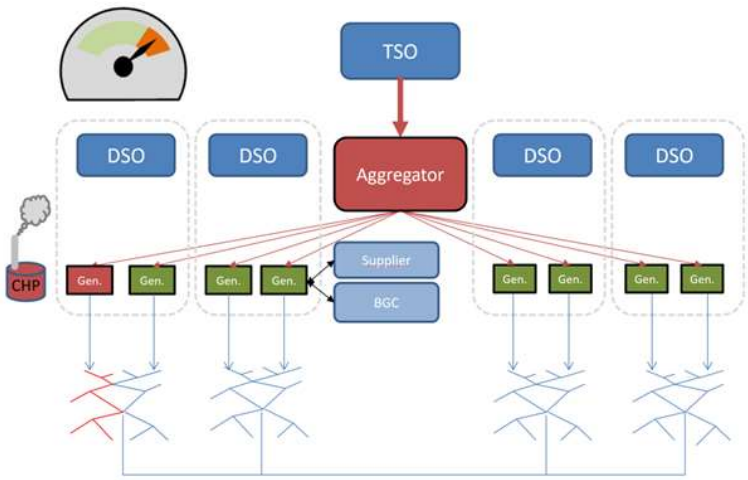
D. Scalability and regulatory framework

71

71

SYSTEM OPERATION & FLEXIBILITY

INTRO



Andoni et al., Blockchain energy systematic review, 2019
PwC, Blockchain - an opportunity for energy producers and consumers?, 2016
https://enerchain.ponton.de/index.php/16-gridchain-blockchain-based-process-integration-for-the-smart-grids-of-the-future

72

72

SYSTEM OPERATION & FLEXIBILITY

Equigy (Europe)

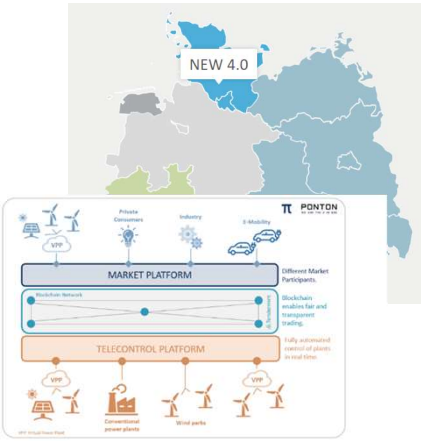
- **Equigy - Crowd Balancing** platform: enables the integration of small and distributed consumer-based units into the electricity-balancing process
- Founding **transmission** system operators: Swissgrid (CH), TenneT (DE-NL) and Terna (IT)
- It helps **balance** the grid and uses blockchain technology to access, **via aggregators**, consumer-based sources of electricity

73 https://equigy.com/

73

SYSTEM OPERATION & FLEXIBILITY

Hamburg Energie (Germany)



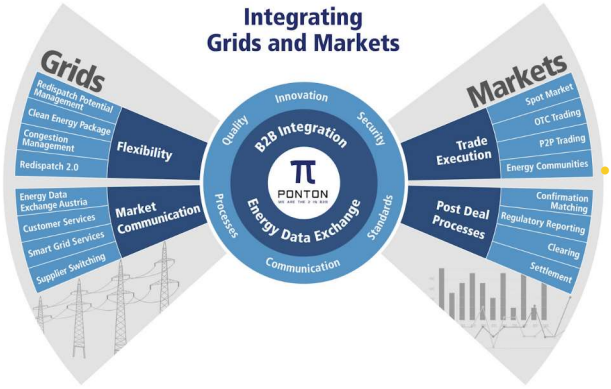
- The German **SINTEG** programme is a regulatory sandbox for the digitalisation of the energy transition
- Within the joint project **North German Energy Transition** (NEW 4.0), the supplier **Hamburg Energie** (with Ponton and others), tested a market platform enabling rapid, flexible and secure regional renewables trading
- The marketplace uses blockchain to prove the origin of electricity and speed up transactions to ensure **continuous trading** and supply

74 https://www.german-energy-solutions.de/GES/Redaktion/EN/News/2020/20200131-blockchain-energy-trading.html
https://www.ponton.de/trading-of-regional-renewable-energy/
German Ministry Economic Affairs and Energy, The handbook for regulatory sandboxes, 2019

74

SYSTEM OPERATION & FLEXIBILITY

Gridchain (Germany)

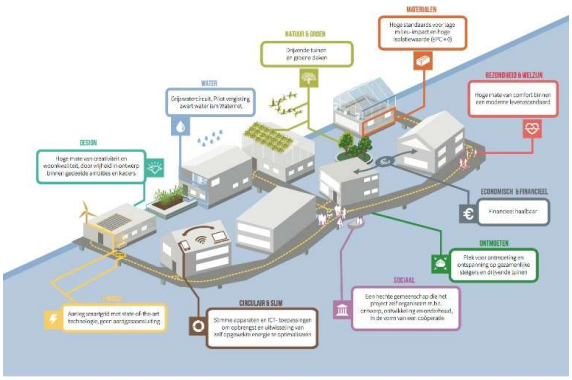


- **Gridchain** (Ponton): blockchain-based pilot software that enables **real-time grid management** in future smart grids
- Aim: increase coordination between transmission/system operators and aggregators on **balancing** services and support **grid congestion** management
- **Prototype** developed upon request of a group of Austrian DSOs, to be now tested on the ground

75 https://enerchain.ponton.de/index.php/16-gridchain-blockchain-based-process-integration-for-the-smart-grids-of-the-future

SYSTEM OPERATION & FLEXIBILITY

Schoonschip (Netherlands)



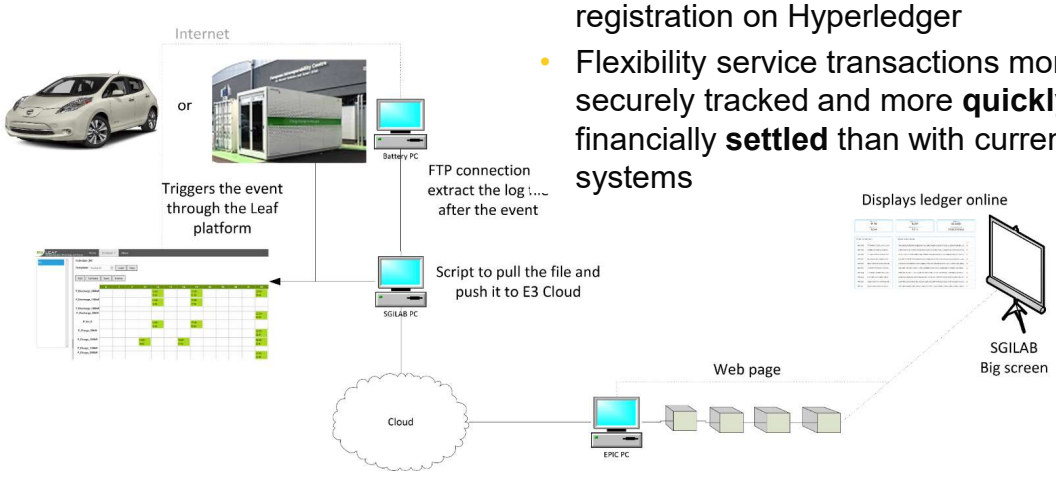
- **Schoonschip** received an exemption from the Dutch Experimental Electricity Law (**regulatory sandbox**) to build a floating water houses complex in Amsterdam connected via a smart grid
- 46 water houses are being equipped with batteries, heat pumps, a heat storage tank and smart appliances
- A **blockchain-based smart grid software controls** individually and collectively the **battery** systems

76 https://schoonschipamsterdam.org/#site_header
van der Waal, Experimentation Energy Law regulatory sandbox, 2020

SYSTEM OPERATION & FLEXIBILITY

JRC Demand Response test (Italy)

- **JRC** testing **Demand Response** flexibility services provided by electric vehicles and storage units
- Close-to-real time and **tamper-proof** registration on Hyperledger
- Flexibility service transactions more securely tracked and more **quickly** financially **settled** than with current systems



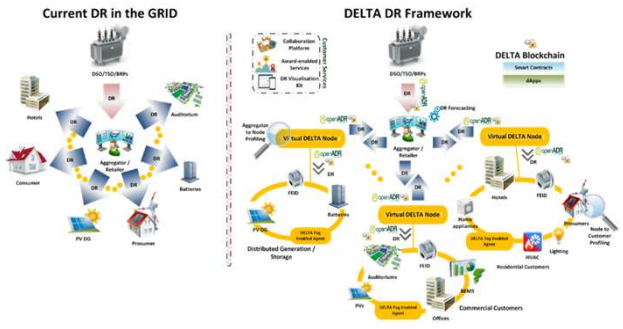
77 Lucas et al., Blockchain Technology Applied to Energy Demand, 2021
https://ses.jrc.ec.europa.eu/digital-grid-interoperability-under-test

77

SYSTEM OPERATION & FLEXIBILITY

Delta2020 (Europe)

- **Delta**: exploiting flexibility of small/medium prosumers, via a novel, secure **Demand Response** Management Platform
- Engage prosumers in both explicit and implicit Demand Response via a social collaboration and incentivization platform and personalized interfaces
- Achieve end-to-end interoperability through open source protocols (e.g. OpenADR)
- Propose new business models and recommendations for policy makers to accelerate market adoption

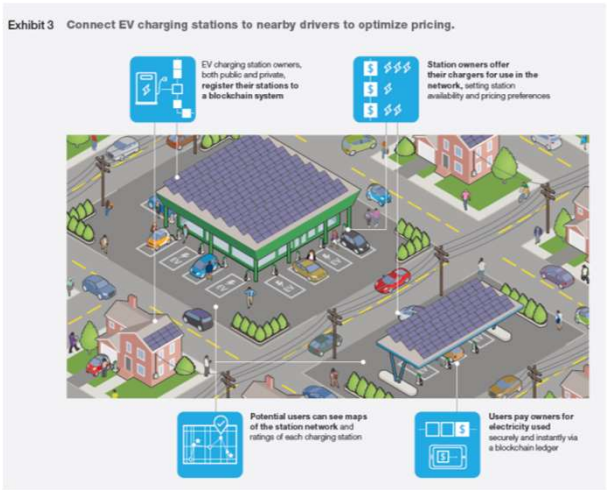


78 https://www.delta-h2020.eu/tag/blockchain/

78

ELECTRIC MOBILITY

INTRO

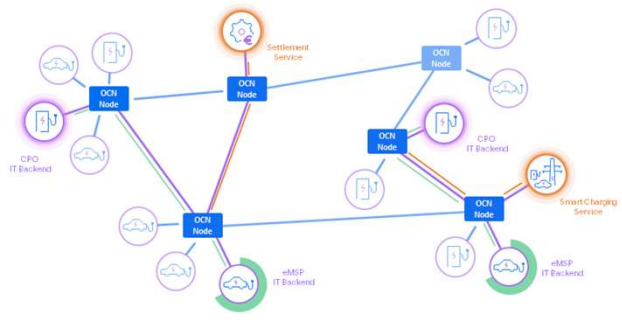


79 Andoni et al., Blockchain energy systematic review, 2019
McKinsey, What every utility CEO should know about blockchain, 2018

79

ELECTRIC MOBILITY

Share & Charge (Germany)



OCN: Open Charging Network
CPO: Charge Point Operator
eMSP: eMobility Service Provider

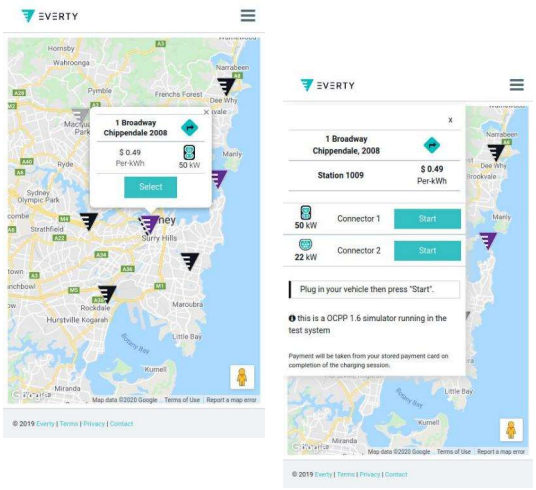
- **Share & Charge**: independent foundation with several companies and projects in the EV and energy sectors
- **Open Charging Network**: Ethereum platform based on the **EV roaming protocol** (Open Charge Point Interface) providing technical **interoperability**
- **p2p payments: t**he Share & Charge **app** connects electric cars with available residential & commercial charging stations and facilitates **payments**
- **Cross-European roaming network** based on blockchain (Oslo2Rome)

80 https://shareandcharge.com/

80

ELECTRIC MOBILITY

Everty (Australia)



- **Everty** platform for **EV charging** that works for private, semi-public or public EV charging infrastructure
- Drivers can charge their EVs at home, commercial or public charging stations while having full control of owned stations and charges
- Network operators can efficiently **manage the assets** in their network, provide **payment** applications via a driver app and view analytics in the Everty **dashboard**

Asset Management | Payment Platform | Dashboard & Analytics

81 https://everty.com.au/

81

Quiz/poll for you

What are some of the main challenges for the implementation of blockchain-based electric mobility projects?

A. Privacy and interoperability

B. Lack of interest of e-mobility companies

C. Lack of blockchain software solutions

D. People acceptance

82

82

3.a POWER SYSTEM BLOCKCHAIN SOLUTIONS

To learn more (1/2)

- European Commission, JRC Smart Electricity Systems and Interoperability
- LO3 Energy
- https://equigy.com/
- Block et al. Market mechanism for energy allocation in micro-chp grids, 2008
- Mihaylov et al., NRGcoin: virtual currency for trading renewable energy in smart grids, 2014
- Pilkington, Blockchain technology: principles and applications, 2015
- Mainelli et al., Sharing ledgers for sharing economies, 2015
- Glaser et al., Beyond cryptocurrencies - a taxonomy of decentralized consensus systems, 2015
- Swan, Blockchain: blueprint for a new economy, 2015
- Liu et al., Energy management of cooperative microgrids with p2p, 2015
- Tai et al. Electricity transactions and congestion management blockchain, 2016
- Olivella-Rosell et al., Day-ahead micro-market design for distributed energy resources, 2016
- JRC, blockchain in energy communities, 2017
- Akter et al., Hierarchical transactive energy management system for microgrids, 2017
- Kang et al. localized peer-to-peer trading among electric vehicles, 2017
- Sikorski et al., Blockchain technology in the chemical industry machine to machine electricity market, 2017
- Green et al., Citizen utilities: the emerging power paradigm, 2017

83

3.a POWER SYSTEM BLOCKCHAIN SOLUTIONS

To learn more (2/2)

- Danzi et al., Distributed proportional-fairness control in microgrids, 2017
- Goranovic et al. Blockchain applications in microgrids overview, 2017
- Long et al., Feasibility of peer-to-peer energy trading in low voltage networks, 2017
- Sorin et al., Consensus-based approach to peer-to-peer electricity, 2018
- Morstyn et al., Bilateral contract networks for peer-to-peer energy trading, 2018
- Aitzhan et al., Security and Privacy in Decentralized Energy Trading, 2018
- Pop et al., Blockchain based decentralized management of demand response, 2018
- Saxena et al., Blockchain transactive energy, 2019
- Salek Ali et al., Applications blockchains IoT review, 2019
- Siano et al., Potentials of distributed ledger technology in local energy markets, 2019
- Troncia et al., Distributed ledger technologies for peer-to-peer local markets, 2019
- Ahl et al., Review of blockchain based distributed energy, 2019
- Power Ledger, KEPCO peer-to-peer energy trading results, 2019
- DOMINOES, Scalable local energy market architecture, 2020
- German Ministry Economic Affairs and Energy, Blockchain based energy systems, 2020
- AloT et al., Open Energy Marketplaces evolution, 2021
- Lucas et al., Blockchain Technology Applied to Energy Demand, 2021

84

3.b

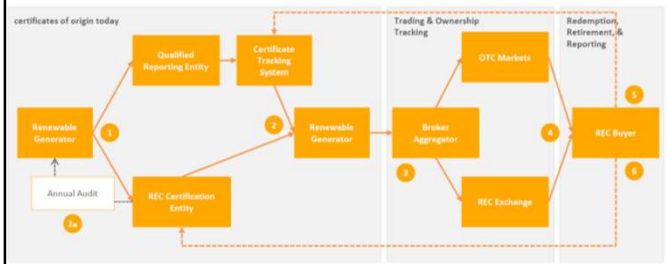
ENERGY SYSTEM BLOCKCHAIN SOLUTIONS

GREEN CERTIFICATES & CARBON CREDITS	ENERGY CRYPTO-ASSETS & INVESTMENTS
Greenchain • Energy Blockchain Labs	Wepower • NRGcoin • Sun exchange • Efforce

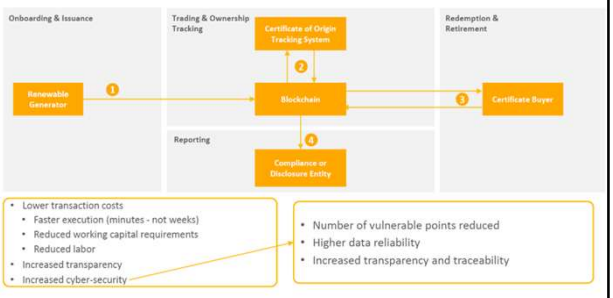
85

GREEN CERTIFICATES & CARBON CREDITS

INTRO



OTC: Over-the-Counter
REC: Renewable Energy Certificate

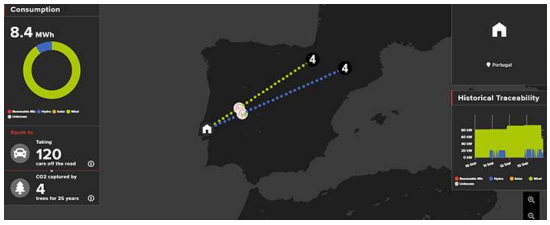


86 Energy Web Foundation, OECD digital security workshop, 2018
PwC Tractebel EC, Assessment and roadmap digital transformation energy sector, 2019

86

GREEN CERTIFICATES & CARBON CREDITS

GreenChain (Spain)



- World Economic Forum listsAcciona **GreenChain** among the energy innovation breakthroughs of the decade
- Demo: trace renewables from Spanish wind/hydro to Portuguese customers
- Scale-up: Blockchain-based real-time tracing of 100% renewable origin of ACCIONA's energy

ACCIONA will supply renewable energy to Telefónica through a 10-year contract

ENERGY | 8 OF JUNE, 2020

— Telefónica has signed, with ACCIONA, its first long-term renewable energy PPA in Spain, reinforcing its decarbonization strategy

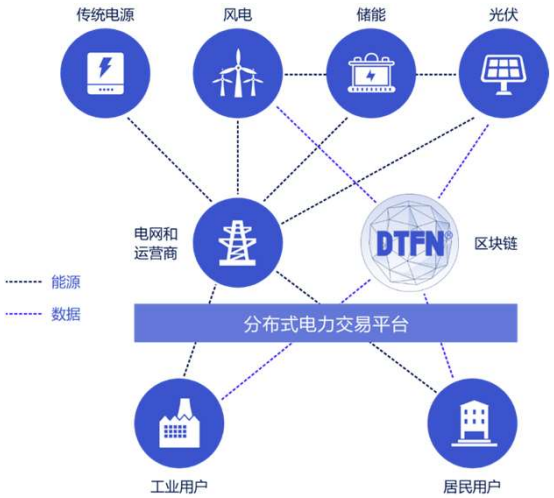
— The deal includes the traceability, available on ACCIONA's GREENCHAIN® platform, of the provided clean energy supply

87 Forbes, 5 companies spearheading blockchain for renewable energy, 2019
WEF, Global Innovations from the Energy Sector 2010-2020
https://www.acciona.com/updates/news/acciona-will-supply-renewable-energy-to-telefonica-through-a-10-year-contract/

87

GREEN CERTIFICATES & CARBON CREDITS

Energy Blockchain Labs (China)



- **Energy-Blockchain Labs**, partnering with IBM to create a **carbon credit management platform** based on Hyperledger Fabric and smart contracts
- Aim: **reduce** the costs of China's carbon trading (based on Carbon Emission Reduction quotas) **by 30%**

88 https://www.nenglian.com/
https://www.ibm.com/case-studies/energy-blockchain-labs-inc

88

ENERGY CRYPTO-ASSETS & INVESTMENT

INTRO

89 Andoni et al., Blockchain energy systematic review, 2019
https://solarcoin.org/

89

ENERGY CRYPTO-ASSETS & INVESTMENT

Wepower (Estonia)

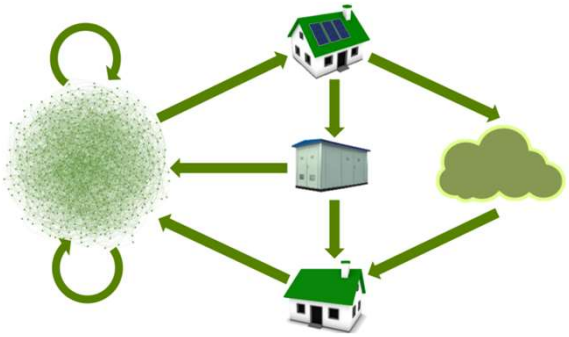
- **Wepower** platform for renewable generators and investors
- Estonian renewable energy tokenised (each **token =** one **Power Purchase Agreement**) and traded via smart contracts
- One year's worth of Estonian production and consumption data tokenised
- Estonian smart meter data platform (Estfeed), providing hourly updates to WePower
- Ethereum scalability issues

90 Andoni et al., Blockchain energy systematic review, 2019
https://www.greentechmedia.com/articles/read/wepower-is-the-first-blockchain-firm-to-tokenize-an-entire-grid#gs.yWqnJ1s
https://medium.com/wepower/wepower-elering-nationwide-energy-experiment-results-revealed-300d65514141

90

ENERGY CRYPTO-ASSETS & INVESTMENT

NRGcoin (Belgium)



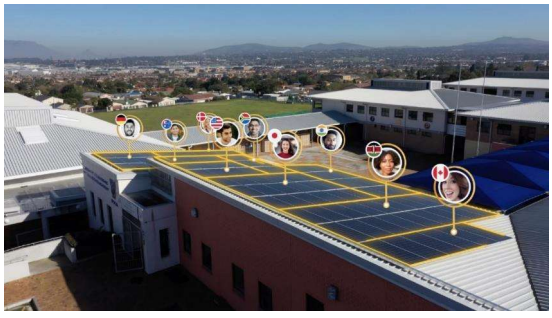
- **NRGcoin** (issued by **Enervalis**) is an incentive and reward mechanism for more efficient use of renewable energy at a local level
- NRGcoin cryptocurrency enables energy system members, including household consumers, DSOs and energy suppliers, to make energy transactions via **smart contracts**
- Issues: blockchain **technology** and smart contracts are rather new and **rapidly changing**. **Regulation** is **unclear** and therefore adoption is slow

91 Mihaylov et al., NRGcoin: virtual currency for trading renewable energy in smart grids, 2014
https://www.enervalis.com/
NRGcoin

91

ENERGY CRYPTO-ASSETS & INVESTMENT

Sun Exchange (South Africa)



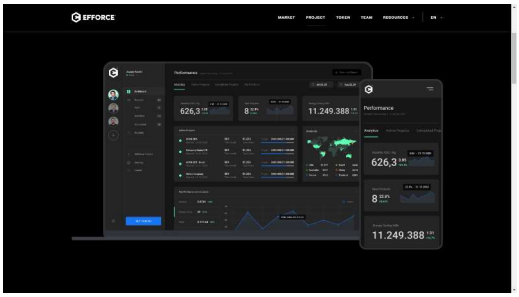
- **Sun Exchange:** crowdfunding platform for **solar projects** in developing countries, allowing investors worldwide to **fund** plants with national currency or bitcoin payments
- Investors can buy solar assets (with **SolarCoin**), which are then leased to consumers in the developing world (e.g. schools and small enterprises)
- **Smart contracts** automatically execute payments from solar producers to investors, as energy is being produced in **near real-time**.
- Blockchain solutions can reduce money transfer costs and increase security in cases of identity theft

92 https://thesunexchange.com/

92

ENERGY CRYPTO-ASSETS & INVESTMENT

Efforce (Italy)



- **Efforce** is a platform for trading **energy efficiency products** worldwide
- Contributors can participate in energy efficiency projects by acquiring **tokenized** future **savings**
- Companies benefit from energy efficiency improvements at no cost and the resulting savings are written in real time on the blockchain
- A **smart contract redistributes** the resulting **savings** to token holders and the companies without intermediaries based on consumption/savings data

93

https://efforce.io/

Quiz/poll for you

Tokenisation creates a digital representation of an asset. Which one of the following is the most correct statement?

A. Tokenisation enables market transactions and co-ownership schemes without requiring data from smart meters and sensors
B. Tokenisation does not enable market transactions and co-ownership schemes and it does not require data from smart meters and sensors
C. Tokenisation enables market transactions and co-ownership schemes and let smart meters and sensors function
D. Tokenisation enables market transactions and co-ownership schemes and it requires data from smart meters and sensors

94

3.b ENERGY SYSTEM BLOCKCHAIN SOLUTIONS

To learn more (1/2)

- https://www.flexidao.com/
- NRGcoin
- https://www.enledger.io/
- Thurner et al., Experiences of project developers around CDM projects in South Africa, 2013
- Dong et al., From smart grid to energy internet, 2014
- Al Kawasmi et al. Bitcoin-based decentralized carbon emissions trading, 2015
- Leonhard, Developing Renewable Energy Credits on Ethereum, 2016
- Imbault et al., Green blockchain: managing decentralized energy, 2017
- Castellanos et al., Cryptocurrency as guarantees of origin, 2017
- Dispenza et al, Energy Efficiency Coin (EECoin), 2017
- EU Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources
- Livingston et al., Applying Blockchain Technology to Power Systems, 2018
- Energy Web Foundation, OECD digital security workshop, 2018
- Yijia et al., Comprehensive review of energy internet, 2018
- Khaqqi et al., Seller/buyer reputation in blockchain-enabled emission trading, 2018
- Wu et al., Application of blockchain sustainable energy, 2018

95

3.b ENERGY SYSTEM BLOCKCHAIN SOLUTIONS

To learn more (2/2)

- Hussain et al., The emerging energy internet, 2019
- Cao, Energy internet blockchain technology, 2019
- Musleh et al., Blockchain applications in smart grid–review, 2019
- Andoni et al., Blockchain energy systematic review, 2019
- Wang et al., When energy trading meets blockchain, 2019
- Hassan et al., Blockchain technologies for smart energy systems, 2019
- PwC Tractebel EC Assessment and roadmap digital transformation energy sector, 2019
- WEF, Global Innovations from the Energy Sector 2010-2020
- Forouli, Fostering sustainable energy through blockchains, 2020

96

3.c

INTEGRATED BLOCKCHAIN SOLUTIONS

MULTI-PURPOSE & INTEGRATED PLATFORMS	IOT, SMART DEV., AUTOMATION & ASSET MGMT
INATBA • Pan-Europe sandbox • Energy Web Foundation • Alastria ID	Swytch • Energinet/IOTA • Oli

97

MULTI-PURPOSE & INTEGRATED PLATFORMS

INTRO

Worldwide policy and business initiatives

Government blockchain initiatives (OECD)

EU Blockchain Observatory and Forum

98 https://oecd-opsi.org/new-opsi-guide-to-blockchain-in-the-public-sector/
https://www.eublockchainforum.eu/initiative-map

98

MULTI-PURPOSE & INTEGRATED PLATFORMS

INATBA (World)

- 2020: **INATBA** (**International Association for Trusted Blockchain Applications**) launched Task Force with Global Observatory on Energy Trading
- Task Force will **compare pilots of Distributed Ledger Technology-enabled P2P energy trading**, and provide a forum for discussion of new **standardisation** recommendations
- International platform for collaboration and information exchange between stakeholders from any sector (i.e. industry, academia, non-profits) on new energy trading models

99 https://inatba.org/news/inatba-launches-task-force-with-global-observatory-on-energy-trading/

99

MULTI-PURPOSE & INTEGRATED PLATFORMS

Pan-European regulatory sandbox

- The **European Blockchain Partnership** is planning a **pan-European regulatory sandbox** in cooperation with the European Commission

Use cases

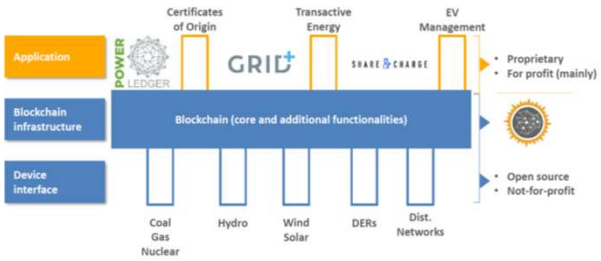
- in the European Blockchain Services Infrastructure (EBSI), the network of distributed nodes across Europe for cross-border **public services**
- and in the health, environment, mobility, **energy** and other sectors
- Targeted areas: data portability, B2B data spaces, smart contracts, and digital identity

100 https://ec.europa.eu/digital-single-market/en/legal-and-regulatory-framework-blockchain

100

MULTI-PURPOSE & INTEGRATED PLATFORMS

Energy Web Foundation (World)



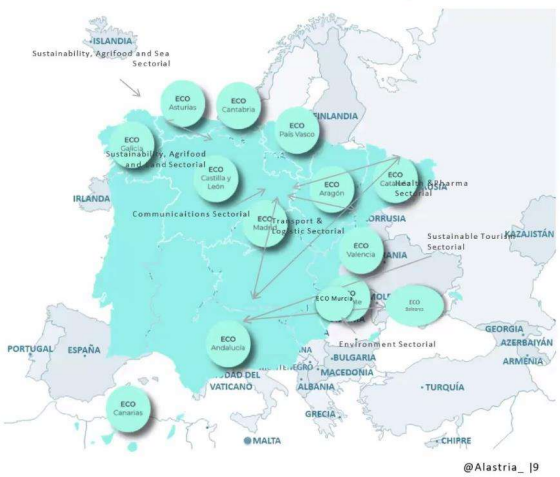
- **Energy Web** (EW) Foundation is a global non-profit organisation leveraging blockchain to achieve a **more transactive energy** system
- World's largest blockchain-for-energy **community of practice**
- **Energy Web Chain:** world's first **open-source**, energy enterprise blockchain platform
- **Energy Web Decentralized Operating System** (EW-DOS), a "blockchain-plus" suite of decentralised solutions (including Energy Web Chain)
- Involved in several initiatives (Power Ledger, Share and Charge,…) and working on **scalability** issues

101 https://www.energyweb.org/
Energy Web Foundation. OECD digital security workshop. 2018
IRENA Brief: Digital applications for the energy transition: blockchain. 2018

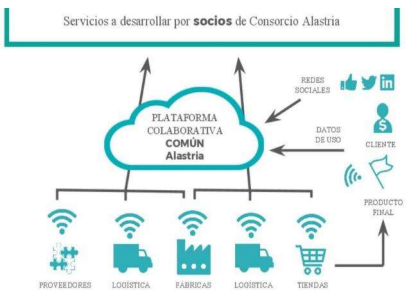
101

MULTI-PURPOSE & INTEGRATED PLATFORMS

Alastria (Spain)



- **Alastria**: non-profit consortium to accelerate digital transformation through blockchain
- More than 560 members from the private and public sectors
- It aims to develop a **EU regulatory compliant** semi-public infrastructure and a collaborative platform
- **Alastria ID**: novel digital identity model



102 https://alastria.io/
EU Blockchain observatory and forum 2018-2020

102

Quiz/poll for you

What is a regulatory sandbox?

A. A facility to test innovative solutions, also for blockchains

B. A platform for playing with cryptokitties

C. A facility to test innovative solutions, but not for blockchains

D. A platform for gaining cryptokitties

INTERNET OF (ENERGY) THINGS

INTRO-1

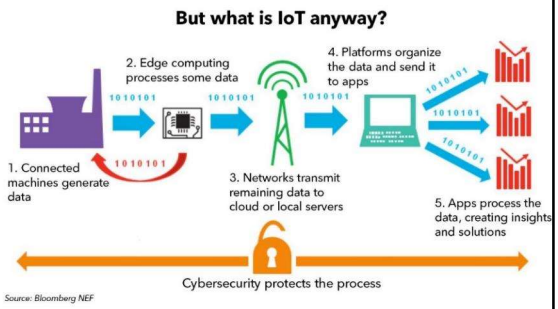
Blockchain-based IoT: potential benefits

IoT architectural shortcomings:

- Central (cloud) and distributed (IoT node) **point of failures**
- **Confidentiality** and **privacy**

IoT-Blockchain integration benefits:

- Enhancing **fault tolerance**
- **Protecting** personal **data**
- Enabling IoT device autonomy
- Guaranteeing **accountability** & traceability
- Handling IoT interactions via **smart contracts**

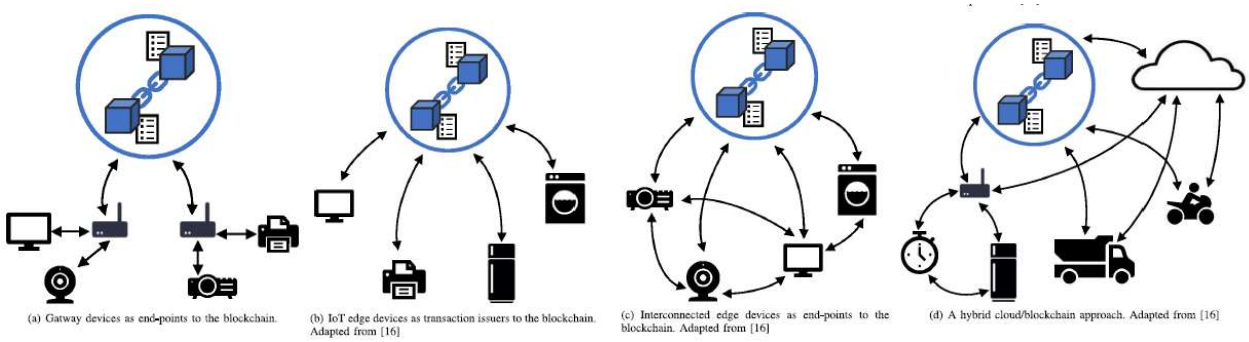


 Salek Ali et al., Applications blockchains IoT review, 2019
https://about.bnef.com/blog/technology-trends-iot-cloud-computing-blockchain/

INTERNET OF (ENERGY) THINGS

INTRO-2

Blockchain-IoT integration paradigms



(a) Gatway devices as end-points to the blockchain.

(b) IoT edge devices as transaction issuers to the blockchain. Adapted from [16]

(c) Interconnected edge devices as end-points to the blockchain. Adapted from [16]

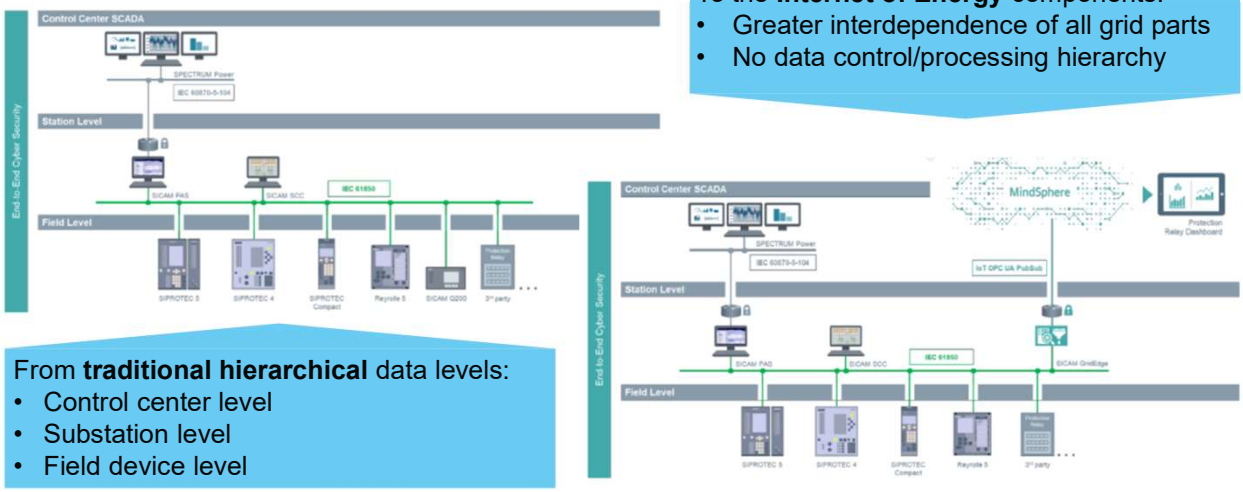
(d) A hybrid cloud/blockchain approach. Adapted from [16]

105 Salek Ali et al., Applications blockchains IoT review, 2019
Reyna et al., Blockchain and its integration with IoT, 2018

INTERNET OF (ENERGY) THINGS

INTRO-3

To the **Internet of Energy** components:
- Greater interdependence of all grid parts
- No data control/processing hierarchy



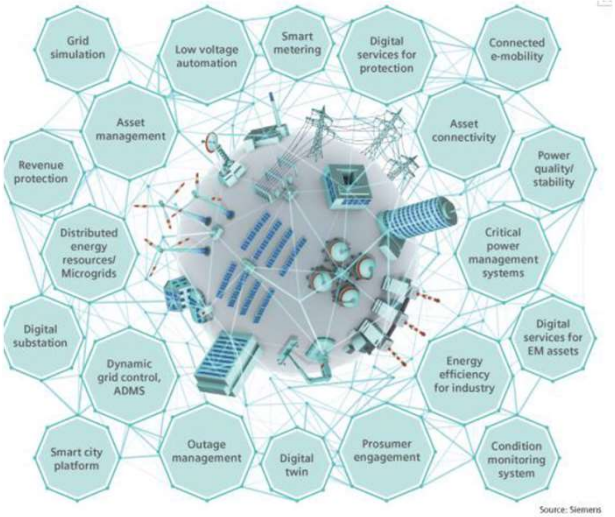
From **traditional hierarchical** data levels:
- Control center level
- Substation level
- Field device level

106 https://new.siemens.com/global/en/products/energy/energy-automation-and-smart-grid/energy-is-going-digital.html

INTERNET OF (ENERGY) THINGS

INTRO-4

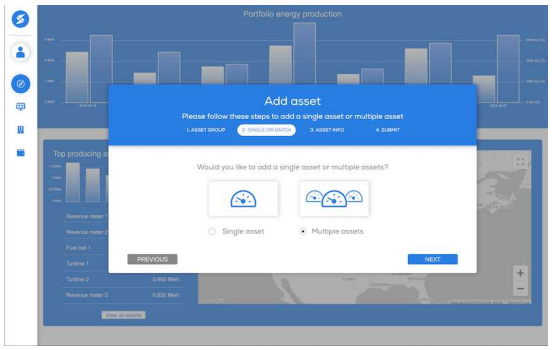
- From **Internet of Things** to **Internet of Energy (Things)**
- New grid **management** models and **tools** for system operation and maintenance improvements
- New **applications** and **services** for a more affordable and sustainable energy supply



107 Unterweger, Siemens, Internet of Energy Things 2018

INTERNET OF (ENERGY) THINGS

Swytch (South Korea)



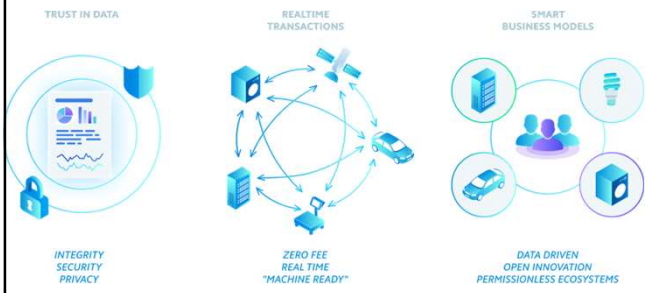
- **Swytch**: operating at the intersection of the IoT and the blockchain
- Swytch enables everyone to get rewarded for sustainability actions which can be tracked and measured using **smart sensors** and **IoT devices**
- **Tokens** are created every time a sustainability action is taken (and measured by IoT sensors/devices)

108 https://medium.com/@openmk/how-swytch-operates-at-the-intersection-of-the-iot-and-the-blockchain-30c47cc6e0f9
https://www.e2m.energy/en/news-entry/Strategic-Partnership-with-Swytch.html

INTERNET OF (ENERGY) THINGS

Energinet-IOTA (Denmark)

- **Energinet & IOTA** signed a Memorandum of Understanding to cooperate in experimentation in the IoT and energy market domains
- Since 2017 IOTA run the Data Marketplace initiative with Energinet and other industrial and IT companies
- New products and services centered on using **IoT devices** to accelerate the green energy transition (e.g. via heat pumps and electric vehicles)



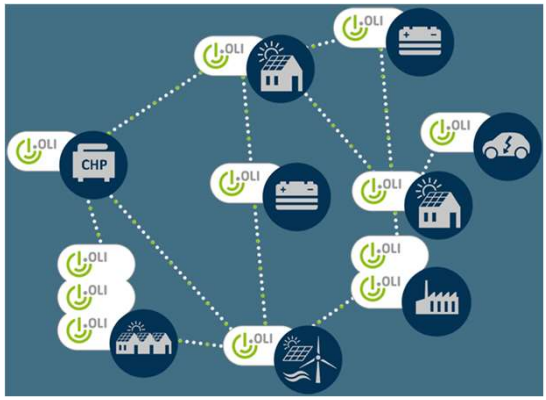
109 https://blog.iota.org/energinet-and-the-iota-foundation-to-drive-internet-of-things-integration-in-the-energy-ecosystem-b29ffa150513/
https://blog.iota.org/part-1-iota-data-marketplace-update-5f6a8ce96d05/

109

INTERNET OF (ENERGY) THINGS

Oli (US)

- **Oli** optimises energy system components (single power plants, demand services, storage providers) and more complex energy systems
- The energy system consists of '**energy cells**' or **virtual power plants** collaborating via blockchain to **exchange energy**
- Blockchains enable virtual power plant operation that can also provide **grid services**



110 https://www.my-oli.com/en/

110

Quiz/poll for you

Which on of the following is the most correct statement about blockchain-IoT integration?

A. The decentralised structure of blockchains can improve the security and privacy of centralised IoT

B. The decentralised structure of blockchains cannot improve the security and privacy of centralised IoT

C. The decentralised structure of blockchains works even if all the IoT nodes are off-chain

D. The decentralised structure of blockchains can improve the security of centralised IoT but not privacy

3.c INTEGRATED BLOCKCHAIN SOLUTIONS

To learn more (1/2)

- https://alastria.io/
- http://www.blockchainresearchlab.org/
- http://www.electricchain.org/
- https://solarcoin.org/
- Zhang et al., Blockchain technique in the energy internet, 2016
- PwC, Blockchain - an opportunity for energy producers and consumers?, 2016
- DENA, Burger et al., Blockchain in Energy Transition German Energy Industry, 2016
- Huckle et al. Internet of Things, blockchain and shared economy applications, 2016
- Ouaddah et al., Towards a novel privacy-preserving control based on blockchain in IoT, 2016
- Holub et al., Mapping Bitcoin's Influence on Academic Research, 2017
- Wang et al., Unified payment method of charging piles based on blockchain, 2017
- Wang et al., Novel electricity transaction mode of microgrids, 2017
- Kim et al., Mobile charger billing system using lightweight Blockchain, 2017
- Qi et al., Shared economy model of charging pile based on block chain, 2017
- Yang et al., Applying blockchain to decentralized operation, 2017
- Hileman et al., Global Blockchain Benchmarking Study, 2017
- Laszka et al., Providing privacy, safety, and security in IoT-based transactive energy systems, 2017

3.c INTEGRATED BLOCKCHAIN SOLUTIONS

To learn more (2/2)

- Kang et al. localized peer-to-peer trading among electric vehicles, 2017
- Nehaï et al., Integration of the blockchain in a smart grid model, 2017
- Munsing et al., Blockchains for decentralized optimization of energy resources, 2017
- Sikorski et al., Blockchain technology in the chemical industry machine to machine electricity market, 2017
- Knirsch et al., Privacy-preserving blockchain-based electric vehicle charging, 2018
- IRENA Brief: Digital applications for the energy transition: blockchain, 2018
- Unterweger, Siemens, Internet of Energy Things 2018
- Reyna et al., Blockchain and its integration with IoT, 2018
- Panarello et al., Blockchain IoT integration, 2018
- Aitzhan et al. Security and privacy in decentralized energy trading through blockchain, 2018
- Knirsch et al. Privacy-preserving smart grid tariff with smart contracts, 2018
- Z. Li et al., Consortium blockchain for secure energy trading in industrial Internet of Things, 2018
- Edeland et al., Blockchain Technology in the Energy Transition, 2018
- Aitzhan et al., Security and Privacy in Decentralized Energy Trading. 2018
- Lombardi et al., Blockchain-based infrastructure for IoT-aided smart grids, 2018
- Guan et al., Privacy-preserving and efficient aggregation based on blockchain, 2018
- SolarCoin, A blockchain-based solar energy incentive, 2018
- IRENA Blockchain Innovation Landscape Brief, 2019
- Salek Ali et al., Applications blockchains IoT review, 2019

113

4 BLOCKCHAIN ENABLERS & ROADBLOCKS

1 ELECTRICITY DIGITALISATION TRENDS & POLICIES

2 DISTRIBUTED LEDGER TECHNOLOGIES

3 BLOCKCHAIN USE CASES & APPLICATIONS

4 BLOCKCHAIN ENABLERS & ROADBLOCKS

114

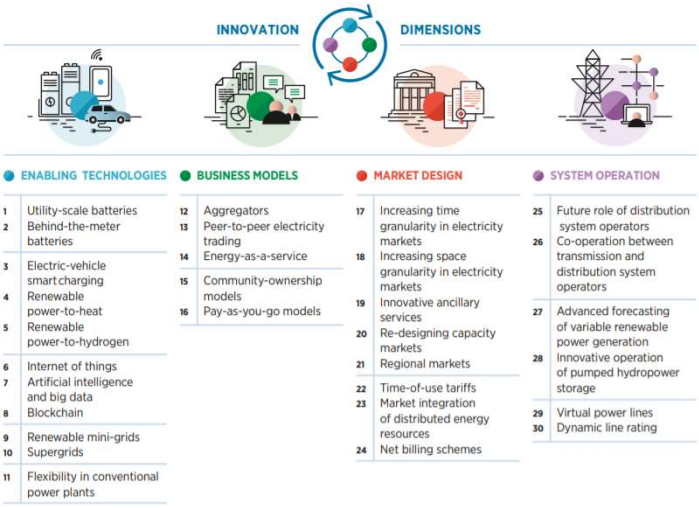
Projects/initiatives we have seen

	METERING & BILLING	ELECTRICITY MARKET & TRADING	SYSTEM OPERATION & FLEXIBILITY	ELECTRIC MOBILITY
POWER SYSTEM BLOCKCHAIN SOLUTIONS	PROSUME • Bankymoon	Brooklyn microgrid • Enerchain • Power Ledger • KEPCO Osaka	Equigy • Hamburg Energie • Gridchain • Schoonschip • JRC DR test • Delta2020	Share & Charge • Everty
ENERGY SYSTEM BLOCKCHAIN SOLUTIONS	GREEN CERTIFICATES & CARBON CREDITS: Greenchain • Energy Blockchain Labs	ENERGY CRYPTO-ASSETS & INVESTMENTS: Wepower • NRGcoin • Sun exchange • Efforce		
INTEGRATED BLOCKCHAIN SOLUTIONS	MULTI-PURPOSE & INTEGRATED PLATFORMS: INATBA • Pan-Europe sandbox • Energy Web Foundation • Alastria ID	IOT, SMART DEV., AUTOMATION & ASSET MGMT: Swytch • Energinet/IOTA • Oli		

115

115

Blockchain as a tool and not as a goal



116 IRENA Brief: Digital applications for the energy transition: blockchain, 2018
IRENA, Innovation landscape for a renewable-powered future, 2019

116

EU's blockchain strategy

- Regulation proposals on **Markets in crypto-assets**
- Regulation proposal on a **pilot regime** for **market infrastructures** based on **distributed ledger technology**

European Commission and European Central Bank exploring a **digital euro**

- **European Blockchain Partnership**
- **International Association of Trusted Blockchain Applications**
- **European Blockchain Observatory & Forum**

European Blockchain Services Infrastructure (EBSI)

Blockchain R&I funding

Regulatory sandbox in financial, energy and other sectors

Interoperability and standards

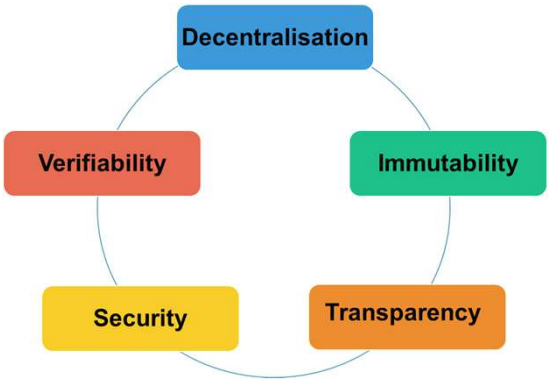
Education and skills

117

117

Blockchain is not the solution to all problems

Key blockchain advantages



"Because many paths lead to interoperability […], we claim to be technology agnostic."

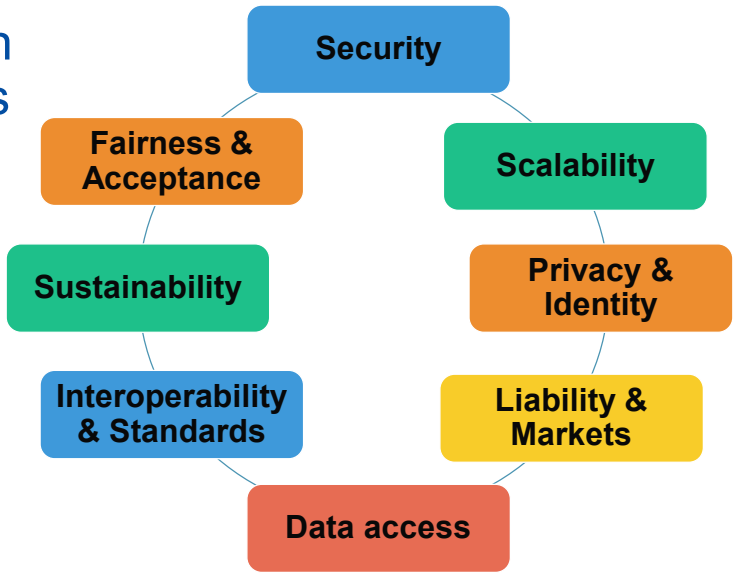
"Apart from blockchain technology there are still other options like direct P2P communication or using a central data hub. But we cannot find out, if we do not enter the helicopter and take a look from above. Let's start!"

118

https://www.ponton.de/b2b-integration/blockchain/

118

Blockchain challenges

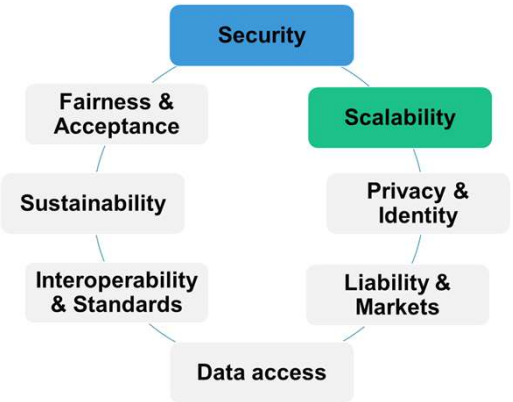


PwC, Blockchain - an opportunity for energy producers and consumers?, 2016
Eurelectric, NERA, Blockchain in Electricity: Critical Review, 2018
IRENA Brief: Digital applications for the energy transition: blockchain, 2018
CEN-CENELEC workshop, Blockchain in the energy sector 2019
EU Blockchain Observatory & Forum, Energy and Sustainability workshop, 2020
European Blockchain Pre-Commercial Procurement, Open Market Consultation Report, 2020

119

119

Blockchain challenges

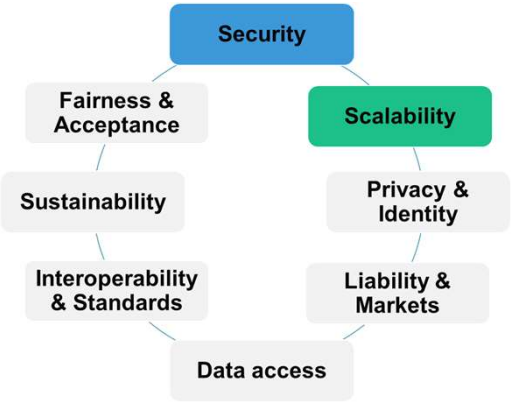


- **Cyber Security**: people as central point of failure (due to poor private key management)
- **Cryptographic Security**: can quantum computing jeopardise public-key cryptography?
- **Asset Visibility**: How accurately the stored and transacted data (i.e. RES energy certificates) represent the real ones (renewable energy)?
- **Security of supply**: can you run a “physical” system just relying on a “virtual” blockchain?
- **Scalability**: How to balance technical innovation with **security** and scalability of solutions?

120

120

Blockchain challenges & actions

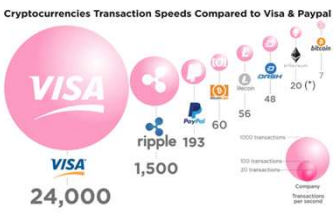


2021 Cybersecurity Directive

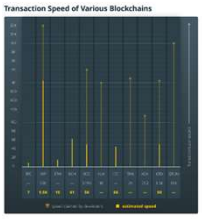
2020 Directive proposal to replace 2016 **Security of Network & Information Systems (NIS)** Directive:

- **resilience of emerging technologies** (e.g. 5G networks, AI, IoT, blockchain)
- **new sectors** (e.g. space) included
- no distinction between **operators of essential services** & **digital service providers**
- **strengthened** roles of **national** authorities and **Cooperation** Group

Blockchain transaction speed (throughput)



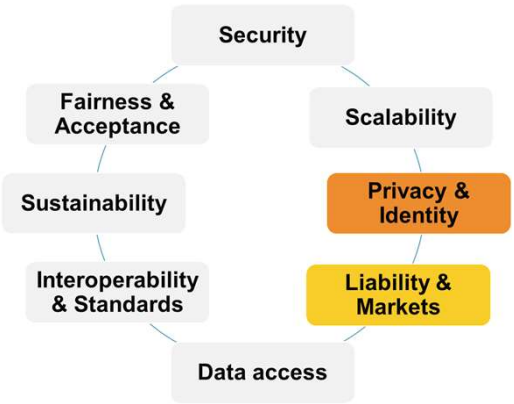
(*) Ethereum 2.0 claims to deliver 100,000 tps



121

121

Blockchain challenges

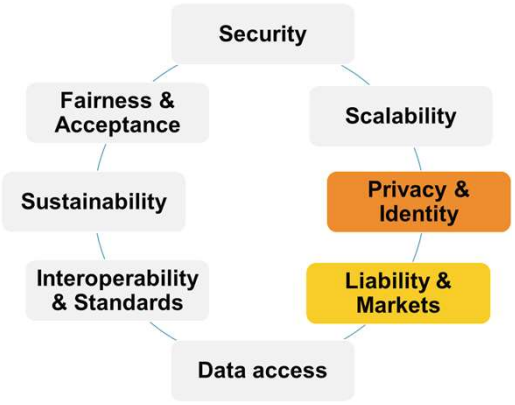


- How to deliver user experience while respecting individual privacy and **identity**?
- **Privacy & data protection**: how to respect the right to be forgotten?
- Who is actually **responsible** for payment settlement/defaults, tampering or blackouts?
- Are all consumers/prosumers going to be **legally** recognised as traders?
- How to make a **contract** of a smart contract?
- How to design a market (i.e. for flexibility services) not discriminating market actors?

122

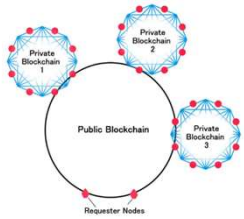
122

Blockchain challenges & actions



123

Combined private-public blockchains



A promising solution for private-by-design IoT data transfer is using a **multi-layer architecture** for blockchains

- Multiple **private blockchains connect to a public** blockchains
- Users in separate private blockchains can choose to **selectively communicate data** to other blockchains

Salek Ali et al., Applications blockchains IoT review, 2019

MULTI-PURPOSE & INTEGRATED PLATFORMS | INATBA (World)

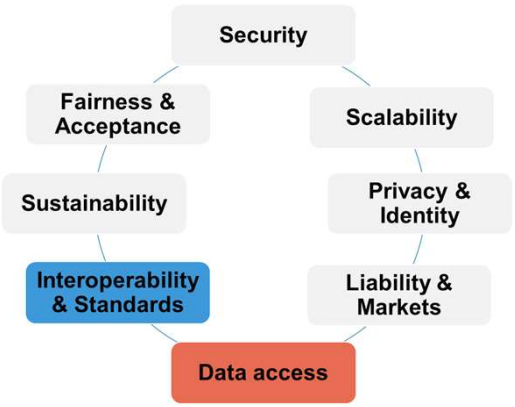
- 2020: **INATBA** (**International Association for Trusted Blockchain Applications**) launched Task Force with Global Observatory on Energy Trading
- Task Force will **compare pilots of Distributed Ledger Technology-enabled P2P energy trading**, and provide a forum for discussion of new **standardisation** recommendations
- International platform for collaboration and information exchange between stakeholders from any sector (i.e. industry, academia, non-profits) on new energy trading models

https://inatba.org/news/inatba-launches-task-force-with-global-observatory-on-energy-trading/

123

123

Blockchain challenges

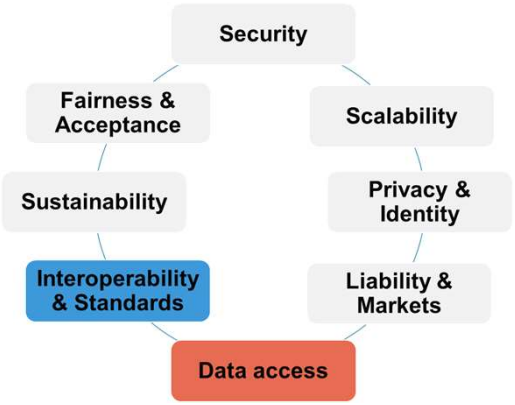


- How to **access and use data** stored on a blockchain to generate an invoice or trigger a smart contract?
- How to ensure **interoperability** of different (e.g. blockchain on- and off-chain networks, smart metering and other) systems?
- How to design **blockchain-ready smart meters**?
- How to balance technical innovation with **interoperability** and scalability of solutions?

124

124

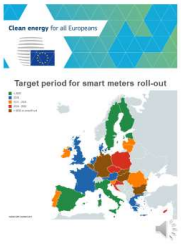
Blockchain challenges & actions



125

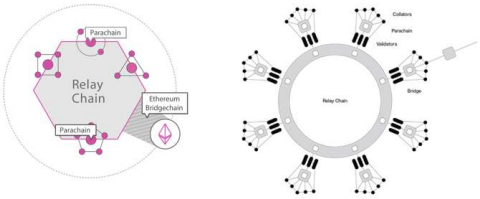
2019 Electricity Directive

- **Smart metering** systems: **266 million smart meters (€46 billion)** in the EU **by 2030**
- **Data** management and **interoperability**
- **Distribution** system operators as neutral **market facilitator** and flexibility services provider
- **Digitalisation** among the tasks of the **Transmission** system operator



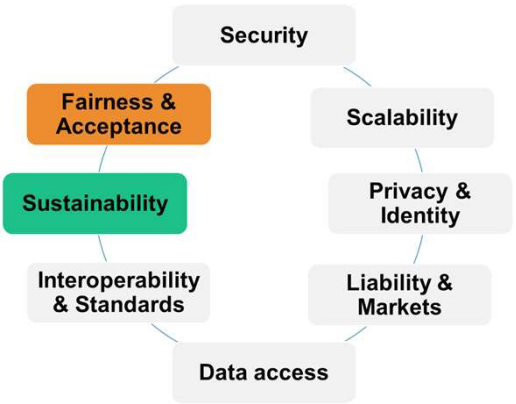
17 Electricity market Directive (EU) 2019/944
EC Tractebel, Smart metering benchmarking report, 2019

Interoperability issues: the Polkadot solution



132 https://medium.com/coinmonks/polkadot-series-part-1-overview-1ad0c7b8d442
https://www.parity.io/a-brief-summary-of-everything-substrate-polkadot/

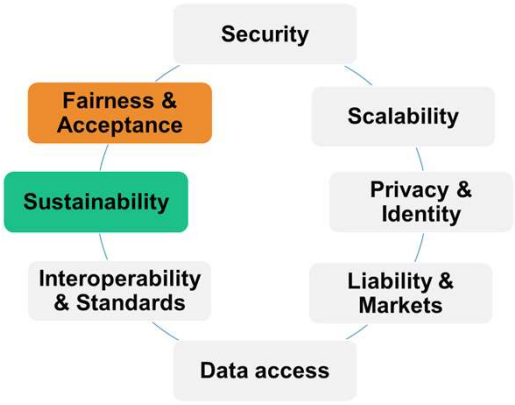
Blockchain challenges



- How to ensure that the blockchain growth is reconciled with its **environmental footprint**?
- How can blockchain contribute to meet the EU's 2050 **climate neutrality** objective?
- How to democratise energy if many users **cannot** (**afford** to) be on board?
- How to **engage** consumers, not just those with a solar panel on the roof?

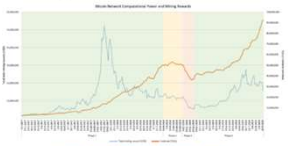
126

Blockchain challenges & actions



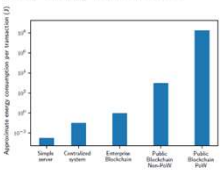
Blockchain energy consumption reassessed

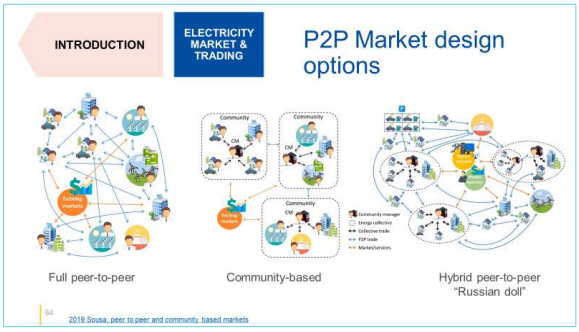
Bitcoin annual **electricity consumption** re-assessed closer to Belgium (**~90 TWh**) (rather than Austria) when considering market dynamics and miners' behaviours



de Vries, Bitcoin consumption underestimated, 2020
de Vries, Bitcoin growing energy problem, 2019
Sedlmeier, The Energy Consumption of Blockchain Beyond Myth, 2020

However **non-Bitcoin** and non-Proof of Work based blockchains display better energy performances





127

127

Quiz/poll for you

What are among the main challenges for blockchain deployment?

A. Security, Privacy and Identity, Interoperability and Scalability

B. Security, Stability, Interoperability and Scalability

C. Security, Privacy and Identity, Decentralisation

D. Transparency, Privacy and Identity, Stability

128

128

What we talked about

1. **ELECTRICITY DIGITALISATION TRENDS & POLICIES** — Digital transformation key **enabler** to reach the **Green Deal** objectives
2. **DISTRIBUTED LEDGER TECHNOLOGIES** — **Blockchain performances** improving while impacting more sectors (beyond finance)
3. **BLOCKCHAIN USE CASES & APPLICATIONS** — Blockchain applications under test all across the **energy value chain**
4. **BLOCKCHAIN ENABLERS & ROADBLOCKS** — **Consistent regulatory** and **legal frame** needed for blockchain upscale

129

129

4 BLOCKCHAIN ENABLERS & ROADBLOCKS

To learn more (1/2)

- European Commission, Legal and regulatory framework for blockchain
- https://ec.europa.eu/digital-single-market/en/news/eus-cybersecurity-strategy-digital-decade-0
- European Commission, JRC Smart Electricity Systems and Interoperability
- International Association of Trusted Blockchain Applications (INATBA)
- Mourshed et al., Smart Grid Futures, 2015
- Zhang et al., Blockchain technique in the energy internet, 2016
- IEA, Digitalization and energy, 2017
- Yang et al., Applying blockchain to decentralized operation, 2017
- European Blockchain Partnership (EBP), 2018
- Panarello et al., Blockchain IoT integration, 2018
- IRENA Brief: Digital applications for the energy transition: blockchain, 2018
- Benedetti et al., Digital tulips return investors ICOs, 2018
- Eurelectric, NERA, Blockchain in Electricity: Critical Review, 2018
- ETIP SNET, Digitalization of the energy system and customer participation, 2018
- McKinsey, What every utility CEO should know about blockchain, 2018
- CEN-CENELEC, White paper distributed ledger blockchain technologies, 2018
- EU Blockchain Observatory & Forum, Blockchain and digital identity, 2019
- CEER Regulatory Aspects of Self-Consumption and Energy Communities 2019

130

4 BLOCKCHAIN ENABLERS & ROADBLOCKS

To learn more (2/2)

- IEEE, Blockchain Beyond Cryptocurrencies: Opportunities and Challenges, 2019
- PwC Tractebel EC Assessment and roadmap digital transformation energy sector, 2019
- Fulli et al., A change is coming: regulation and innovation electricity markets, 2019
- JRC, Digital transformation in energy and other sectors, 2019
- IRENA, Innovation landscape for a renewable-powered future, 2019
- IRENA Blockchain Innovation Landscape Brief, 2019
- Global Market Insights, Blockchain in Energy Market, 2019
- Diestelmeier, Changing power consumers with blockchain policy implications, 2019
- CEN-CENELEC workshop, Blockchain in the energy sector 2019
- Atlam et al., Technical aspects of blockchain and IoT, 2019
- EU Blockchain Observatory & Forum, Energy and Sustainability workshop, 2020
- EC Workshop: Data Driven Energy Services. How to Engage Consumers, 2020
- European Blockchain Pre-Commercial Procurement, Open Market Consultation Report, 2020
- OECD, Digital Economy Outlook, 2020
- EU Council Conclusions on Regulatory Sandboxes, 2020
- OECD, Attrey et al., Role of sandboxes in digital age, 2020
- Yassine et al., Blockchain cyber security and privacy, 2020
- van der Waal, Experimentation Energy Law regulatory sandbox, 2020

131

Electricity sector digitalisation and blockchains

Acknowledgements

This material greatly benefited from inputs and reviews from several JRC colleagues including Marcelo Masera, Igor Nai Fovino, Dimitrios Thomas, Alexandre Lucas, Antonios Marinopoulos and Vangelis Kotsakis.

Disclaimer

The information and views set out in this presentation are those of the author and do not necessarily reflect the official opinion of the European Union.

Gianluca FULLI
gianluca.fulli@ec.europa.eu
https://ses.jrc.ec.europa.eu/

132

European Commission

132