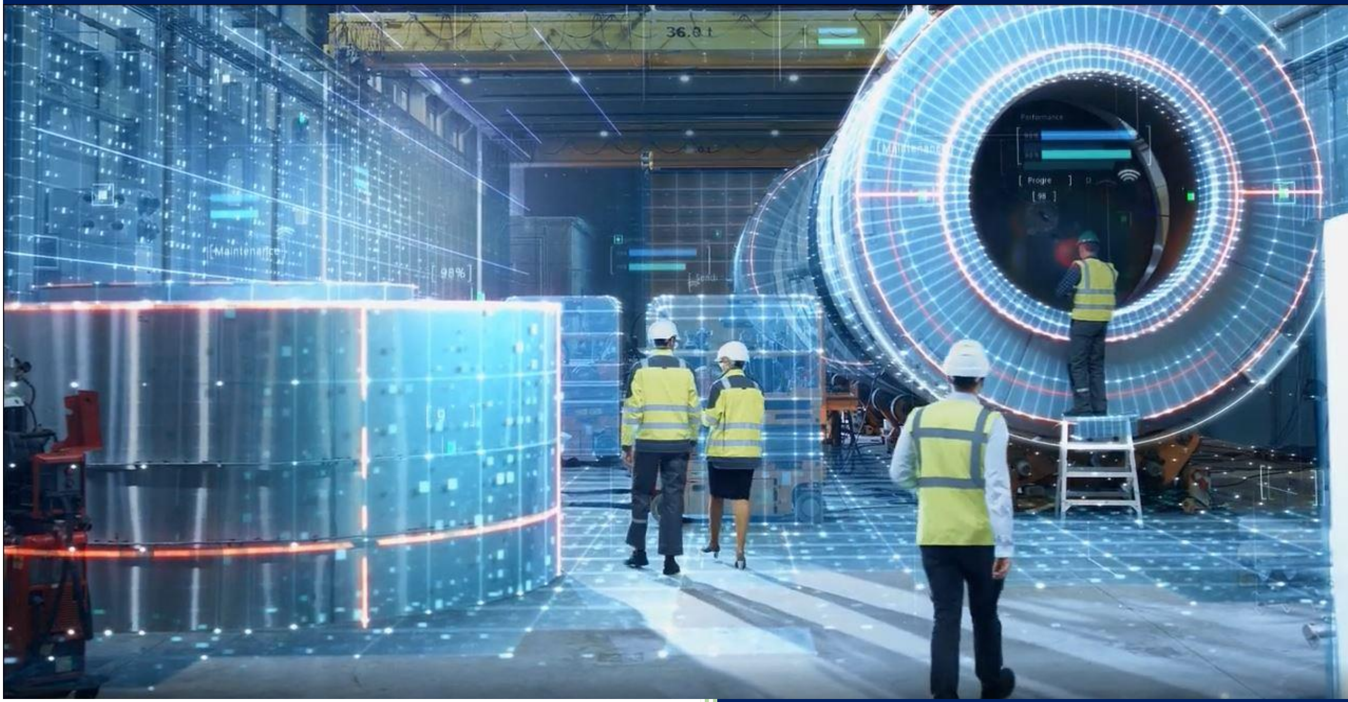
Digital twinning, cyber physical system, carbon emissions – a systems approach.



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DIGITAL TWINNING AUSTRALIA

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Terminology

Acronym	Definition
BIM	Building Information Model
CPS	Cyber Physical System
DTw	Digital Twin
dtAI	DTAs Artificial Intelligence
dtML	DTAs Machine Learning
CMMS	Computerised Maintenance Management System
CPS	Cyber Physical System
DTA	Digital Twinning Australia
ERP	Enterprise Resource Planning
GHG	Green House Gases
GenAI	Generative Artificial Intelligence
Cx	Customer experience
IFRS S1	International Financial Reporting Standards – General Requirements for disclosure of sustainability related financial information
IFRS S21	International Financial Reporting Standards – Climate related disclosures
LoD	Level of Detail
NGER	National Greenhouse & Energy Report
MVP	Minimum Viable Product

Title

Digital twinning, cyber physical system, carbon emissions – a systems approach.

How a digital Twin system, underpinned by a cyber physical system infrastructure improves both carbon emission reporting and operational efficiency – a systems approach.

Abstract

The paper will consider how inter-connected digital twins in a cyber physical system both enhances and changes the system for carbon emissions reporting, as well as providing operational benefits to the organisation. The operational benefits can also act as a re-enforcing loop to reduce carbon emissions potentially further. Adopting a system thinking approach it reviews the total reporting chain from source of emissions to global reporting consolidation and also how innovative feedback from along that chain can also change operations to enhance emissions reduction. By considering the overall system in a holistic manner, we can make improvements both to reporting accuracy and traceability, as well as operational efficiency.

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Introduction & systems thinking

Digital technology is being used extensively in various activities to limit climate change and its impacts and this paper specifically focuses on the accurate and reliable tracking and reporting of carbon emissions (GHG reporting) and the significant benefits of utilising inter-connected Digital Twins (DTw) in a Cyber Physical System (CPS) to capture, analyse and consolidate accurate data for subsequent automated reporting. By understanding both the end-to-end process and requirements from the parties involved and then applying systems thinking, we identify substantial improvements both in the system as well as in reduction of carbon emissions.

Systems thinking will help us to understand the systems structures, feedback & reinforcing loops, constraints, mental models and "soft 'issues" that influence the system operation and therefore opportunities for improvement. (Meadows & Wright, 2008)

For the purpose of this paper, the boundaries are set starting with the generic physical assets that generates the carbon emissions. Those emissions are captured in data and consolidated within the organisation, to reporting through various government and regulatory authorities and ultimately to aggregation at a global level.

While it is acknowledged that digital twins can also be used during the design and construct stage to limit embodied carbon in the asset, which is certainly an important and current strong interest in the construction industry in particular, the focus of the paper is on the operations stage of assets. Some writers have also discussed linking multiple digital twins and cyber physical systems together across organisational boundaries into a "system of systems", which brings further benefits, but again outside the boundaries we have set for this paper. (An example is an interconnected weather, wind power generator, smart home power demand and an electricity distribution system - as quoted by Dietz and Pernul, 2020). A further issue we do not address here is what writers are calling the "rebound effect", where unless constraints are imposed, digital solutions can increase the demand for and use of the solution, which effectively increases the amount of carbon emissions from the original baseline (Widdicks, 2023).

As a further constraint we will focus on scope 1 and 2 emissions, where there is currently more reporting activity and regulations in place, since scope 3 is significantly more challenging involving multiple parties from upstream and downstream supply chain with data interoperability issues. The diagram below shows the scope 1,2 and 3 emissions sources.

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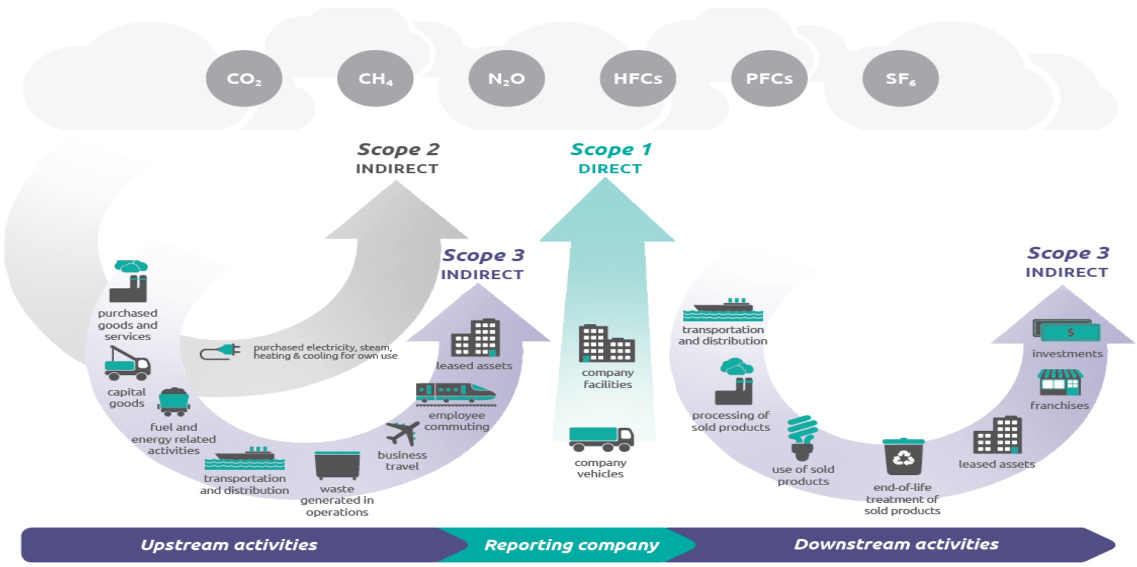

Figure 1 - Scope 1, 2, 3 emissions sources across value and supply chain (source GHGprotocol.org)

Emissions Reporting Challenges

Current Carbon reporting systems

As noted above, the focus is on scope 1 and 2 carbon emissions, since scope 3 relies on input from the supply chain, where currently the quality of data varies significantly. There are suggestions of a platform independent data sharing service where organisations along the supply chain contribute data based on industry standards, however this will take time, effort and considerable goodwill amongst various players to establish a credible working solution.

Thinking about the systems structure, Figure *2* shows generic carbon emissions reporting within an organisation, which as noted is manually intensive and error prone. A new sub-industry has now emerged for auditing the organisations reporting and there are still significant concerns about "green washing" of estimated and sometimes "manufactured" data.

Internal stakeholders will include operations staff and management, potentially a newly established group to analyse and consolidate the data, passing this to Finance team for incorporation into statutory and public relations reporting. For public companies, especially Boards of Directors, there is a need to assure themselves that the organisation is both compliant and that the data has been validated by independent audit.

After the data is reported by the organisation, there are a long chain of other stakeholders as noted below:

- Regulators to ensure compliance.
- Industry groups who want to understand how their industry is performing, often for a public relations type exercise, but also for sharing useful knowledge on techniques being applied.
- State, Federal or National governments who have made commitments to reduce carbon need to consolidate the information to understand how they are tracking and promote their green credentials.
- This is further aggregated at a global level with organisations, such as UN and others, comparing the activities and results from various countries.
- Financiers, investors and shareholders also will want to scrutinise the organisation's results when considering further investments, or where to place their investments in "ethical" organisations.
- The media and community will also be interested about how organisations are progressing towards carbon reduction and can apply some pressure to organisations in various ways, such as social and other media and particularly through organisations and community purchasing decisions.

We can therefore note that there is intense scrutiny on how organisations report carbon emissions, which means the system needs to be reliable, transparent and defensible. There are significant organisations who now have that in place, one example being Nokia in Finland and their annual People and Planet Report (Nokia, 2022).

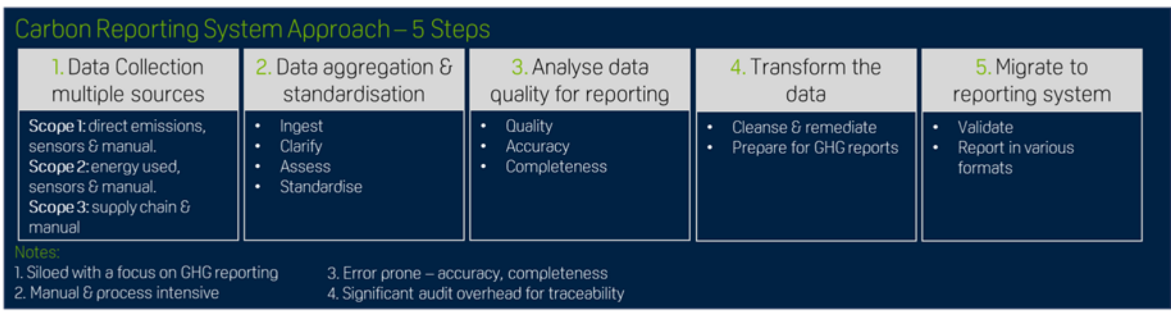

Figure 2. Current 5 step reporting approach.

Carbon emissions reporting Challenges

Most carbon reporting will rely on data collection using estimates, often published by manufacturers or the industry and based on average data under normal operating conditions. This will require considerable manual effort to obtain and process the data, with the potential for errors of all types to occur. Also, the asset may not be operating under normal conditions, depending on age, location, environment, effective maintenance and operator capability.

The data is collected from various silos in the organisation by a group responsible for consolidating the carbon emissions reporting and potentially they are not conversant with the individual asset and its operating mode and condition.

As noted in Figure 2 above, there is a need for independent data cleansing to both standardise and validate the data and ensure its completeness as much as possible. This whole process adds no value to the frontline operations staff, where it is simply another overhead that they need to work with.

Those responsible for consolidating the data need to be able to provide some level of traceability to convince auditors of the "reliability" of the data. Then there are considerable overheads in an independent party auditing the organisations data to ensure its validity for reporting. A good DTw capturing carbon would remove the cost and automate reporting.

Since the data is estimated at source, this means that estimation errors are compounded at each level of aggregation, both within the organisation, across industry and by country and therefore ultimately globally.

Why digital twinning

Cyber Physical System solution

A Cyber Physical System (CPS) is a federation of interoperable Digital Twins. A Digital Twin is centred on creating a virtual representation for simulation and analysis and varies from basic to advanced in quality, whereas a cyber physical system is focussed on the integration and interaction of computational and physical processes for monitoring and control. This means that a CPS is comprised of the inter-connected higher quality Digital Twins, performing different functions whilst remaining interoperable with each other.

In the context of the resources industry, taking a processing plant as an example, a Digital Twin of this plant would monitor the performance of the pumping system and predict when maintenance is required, or it would be used to simulate and analyse the pump distribution and energy consumption. A Cyber Physical System of the processing plant would be centred around the sensors and control systems constantly interacting with the pump's physical components to operate at maximum efficiency, which is acting like a feedback loop with computational smarts in the backend infrastructure. An example of a computational process here could be around the tolerance levels of the pump vibration. As the pump vibration breaches a certain tolerance level, the Cyber Physical System can modify the pump's performance to remain under this tolerance level and can also consider other factors which are influencing this breach such as pipe flow rate or fluid viscosity.

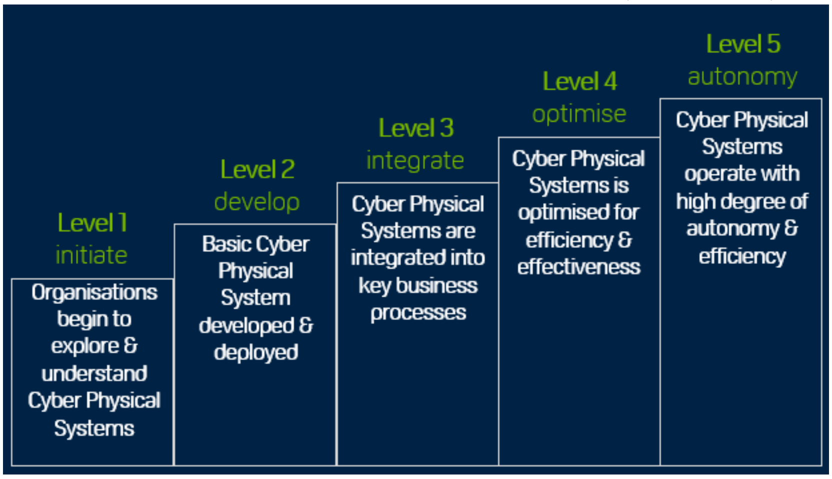

Figure 3. Levels of CPS maturity.

Cyber Physical System maturity levels range from level 1 to level 5 based on capabilities [see Figure 3] relating to automation, integration and interoperability. Most organisations would currently sit in either level 1 or 2 as the maturity overall for CPS implementation is low.

Data interoperability remains one of the barriers for an organisation truly achieving transformational change, mainly due to factors such as;

- Diverse and fragmented data sources
- Vendor-specific solutions
- Legacy Systems
- Standardisation challenges
- Data silos
- Regulatory compliance.

Data interoperability is a key benefit for implementing a Cyber Physical System solution. Due to data sets being traditionally siloed and sourced from different systems and databases, there exists a significant challenge in normalising and standardising the data so that it can be utilised effectively. The Cyber Physical System Infrastructure CPSi utilises a common data model framework to provide a consistent format and structure. Using the physical asset as the anchor, all relevant data sets are associated with the particular asset, leveraging existing asset IDs and hierarchies to organise and structure the data.

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The CPS technology is addressing the asset life cycle issues commonly faced by organisations. Whilst the benefits for using digital twins and virtual simulation during the design and construction phases are well known, the real value comes during the operate, maintain and end of life phases. Traditionally, Building Information Models [BIM]s are mainly utilised for the design to construct phase and are shelved once the operate and maintain phases begin. CPS technology is enabling BIM models to be capable of managing critical operational functions and provide numerous benefits for the organisation through enhancing performance monitoring, such as KPI tracking, cross functional collaboration and lifecycle cost optimisation. The issues around end-of-life decommissioning are also addressed using a CPS through sustainable practice insights, such as understanding environmental impact and providing continuous improvement data for future end of life scenarios such as effective recycling options.

Cyber Physical Systems are composed of advanced backend infrastructure to support the technology platform.

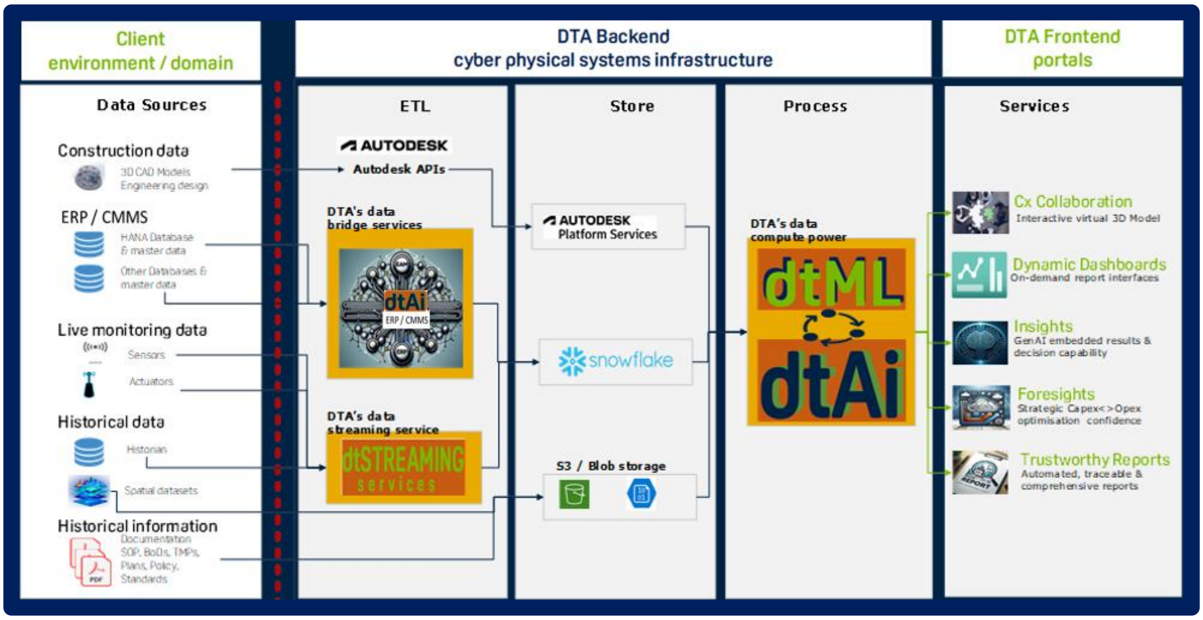

Figure 4. DTw and CPS architecture

The key elements include the data source collection, the ETL (extract, transform and load) phase, the store phase, the process phase and the services delivery. This infrastructure facilitates ingestion of all types of data sets, such as IoT Sensors, historical batch data, document-based data, geospatial data, Enterprise Resource Planning [ERP] and computerised maintenance management system [CMMS] data. By bringing all this data together, it allows for a contextual view of the asset and its operation and status.

Data Sources: The application ingests client data from numerous databases and systems, including 3D Geospatial data, historical geospatial data, ERP/CMMS data, satellite data streams and any other bespoke application source.

Extract Transfer Load [ETL]: This phase is handled by DTA's proprietary data validation and streaming services for all geospatial and live data sets for immediate geotechnical prospectivity analysis. ERP/CMMS data ingestion is handled via DTA's proprietary *Bridge* technology.

Store: The transformed data is stored in various databases depending on the type of data, such as SQL, DocumentDB and PostgreSQL.

Process: This phase utilises DTA's proprietary processing and compute power technology to process the commodity, prospectivity and infrastructure data.

Services: The application will provide several service options: Cx collaboration, dynamics dashboards, insights, foresights and reports.

The CPS solution is also capable of delivering accurate and reliable carbon traceability for the assets and systems being monitored. This occurs through tracking the asset's performance and emissions output down to a granular level, which means the individual pieces of equipment and machinery, where the level of granularity is dependent on the system and equipment as well as location and environment. Real-time analysis on this information incorporates emission calculation algorithms to deliver multiple insights for the user, defined as "uplift" and "delift", which relates to its emissions output based on a target baseline. This information is providing data traceability from the source level to the reporting level, meaning factors such as electricity consumption and carbon outputs are understood at the equipment level rather than the plant or facility level, providing more transparent and accurate information for the organisation.

A critical component of Cyber Physical Systems is the computational layer that sits across the system. This enables the CPS to implement machine learning algorithms and Artificial Intelligence rules to the data in real-time, providing insights and analysis on the data. Advanced AI including cutting-edge GenAI (generative AI) and machine-learning models are utilised across the Cyber Physical System infrastructure, such as; predictive maintenance, anomaly detection, control and optimisation, simulation and testing, environmental monitoring and reinforcement learning. These capabilities form important tools for operational efficiency leading to reduced emissions.

Implementation tactics

The roadmap to implement a Cyber Physical system solution involves a rigorous and tested pathway to ensure clients can obtain maximum value from their CPS solution. Initially it is necessary to understand the existing problems and issues the client is facing and define the required data sources which impact the businesses' KPIs. The below schematic illustrates a typical roadmap for Cyber Physical System (CPS) implementation, leveraging the standard design thinking methodology framework.

During the process of developing CPS technology for a client, it is essential to begin with a minimum viable product [MVP]. This involves choosing a critical asset/s that drives the businesses Key Performance Indicators (KPIs) or Return on Capital Employed [ROCE] or Weighted Average Cost of Capital [WACC] and provides immediate substantial value for a vertical slice of users. The CPS is designed to be easily scalable and is implemented with a modular approach during the scale up development.

In implementing a quality Digital Twin underpinned with Cyber Physical System infrastructure, the crucial step is identifying and tracing critical data sets aligned with the critical reports. This involves understanding existing databases and data sources within the organisation and discerning vital data elements like database schemas, key flows, sensor data and data structures.

Such an approach enables the development of robust data models and architectures, essential for an effective CPS infrastructure. Utilising tools like data traceability maps and line of sight schematics can further aid in pinpointing data that significantly impacts operational efficiency or capex-opex trade off demands and helps in achieving strategic objectives, including reduced carbon emissions.

Data typically utilised for operational purposes can be leveraged for corporate carbon/emissions reporting requirements. Performance metrics/baselines from performance data can indicate/predict likely emissions outputs at the equipment/system level. Feedback loops & computational layers enable equipment performance alterations in real time and can provide real-time (more near-real time) insights into emissions output.

When implementing digital technologies, it is best to start with several potential use cases, which will allow an overall interim roadmap to be developed. This enables a promising initial small feasible project to be identified and initiated which is most cost-effective framework. Once completed it will provide an improved understanding of the potential and allow a rigorous business case to be developed. The business case will also identify measures for the benefits as well as a means of tracking them at appropriate stages. DTAs approach [see Figure 5] includes the development of a Basis of Data Design to ensure that the DTw and CPS effectively consolidate and utilises data for the overall benefit of the organisation in achieving its strategic objectives.

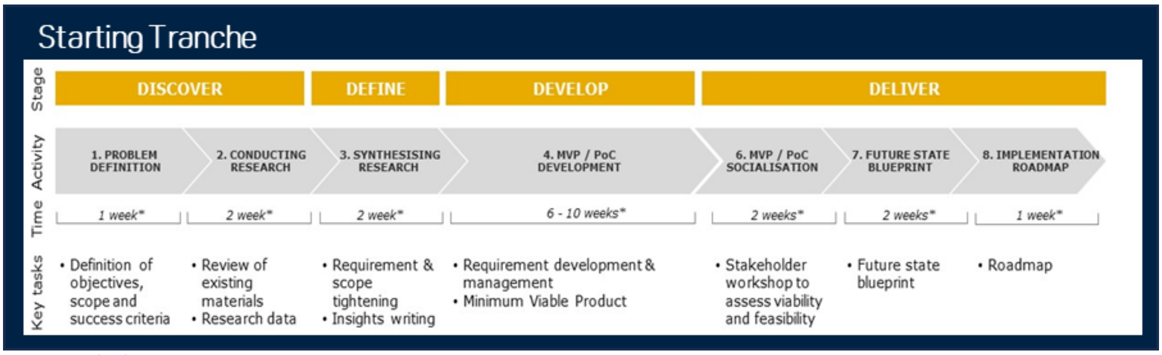

Figure 5. CPS implementation roadmap.

Digital-Cyber Benefits

Case Study

Context

A case study is described with a tier 1 miner's operating processing plant to develop emission tracking, traceability, automated reporting and analytics through the implementation of a cyber physical system solution. The solution utilises more than 100 different data sources related to asset performance, equipment and finance to generate more accurate emission reporting.

Challenge

Common challenges with organisations around environmental and emissions reporting include the accuracy and granularity of the emissions data. For this case study, an operating processing plant is utilised to resolve the following complex questions:

1. Can green vs. *will never be green* be validly defined?
2. How can emissions be traced from asset component to Executive reports?
3. What is the impact of green transition on capital planning?

Solution Delivered

Through utilising the Cyber Physical System infrastructure, granular data for the equipment and processes was captured including performance data, power consumption, maintenance history, condition monitoring and alarm outputs to provide more accurate reporting on emissions. This data when paired with standard emissions calculation algorithms provided automated on demand emissions data for reporting, including Carbon dioxide equivalent (CO_2-e) emissions, Material waste, water waste and air emissions (dust). Emissions data sets are categorised via Scope 1, 2 or 3 sources.

Along with the CPS technology solution itself, other critical deliverables included:

- Basis of Data Design – Provides comprehensive outline of key data parameters and decisions when developing the project's design and implementation.
- Traceability map – Defines critical data points and flows within the processing plant to understand at the asset level specific emissions data.
- Emissions roadmap – Roadmap that details the pathway towards the site successfully capturing all relevant emissions data at the appropriate level as well as future actions required to be compliant with reporting standards.

Value Created

Amongst the multiple economic benefits, the Cyber Physical System technology enables data to be traced from the source to emissions report – reducing the risk of greenwashing and reporting errors. The CPS enables on demand emissions performance insights, foresights and compliance with reporting standards and provides on demand data for emission reporting standards, both for current reporting requirements (NGER) and future requirements (UN, Paris accords).

DTw solution Benefits

Earlier we considered the structures of the current carbon emissions reporting system and its challenges and most of these are resolved through the adoption of a digital twin, which captures accurate data at source and therefore eliminates the compounding estimation error in the current system, as well as automating the reporting systems more. Together with the operational efficiencies obtained this will change the typical mindset so that carbon emissions reporting is not seen as an overhead but as beneficial to the organisation in multiple ways. The DTw would provide economic benefits in addition to carbon reporting so that it would be of no cost to the organisation long term.

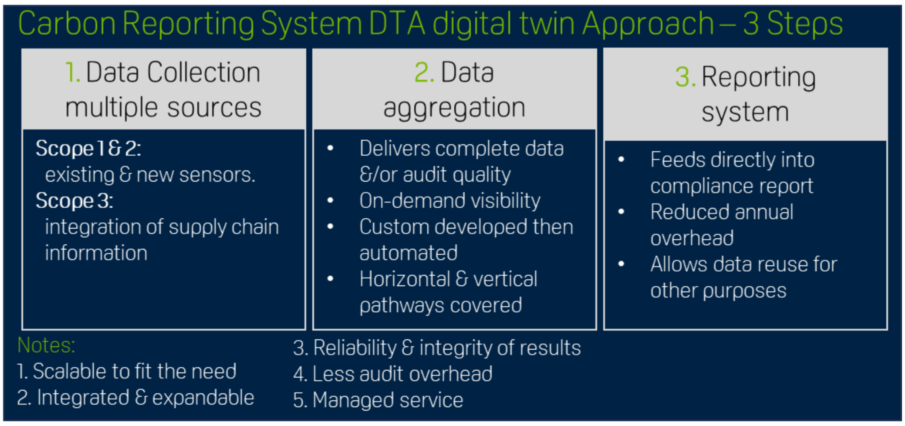

Figure 6. DTA 3 step approach

There are significant benefits from a digital twin and cyber physical system across the organisation, so we have categorised these in the table below to enhance understanding.

Benefits categories	
Carbon emissions reporting	• Increased data accuracy. • Data collection and processing efficiency. • Reporting transparency and accountability. • Significantly reduced audit overhead. • Trust in published data – corporate reputation. • Fulfilled compliance obligations. • Ability to expand scope of collection as required. • Reduction in carbon – use cases - (Automation World (2023) *"In late 2022, Ecolab and Siemens announced a partnership to develop a digital twin program called Climate Intelligence. Climate Intelligence pilots have shown that the technology can facilitate approximately a 5% overall reduction in emissions and pays for itself through efficiency gains".*
Operations	• Improved maintenance/refurbishment based on asset condition. • Reduced asset life cycle costs. • Feedback loop to show how to reduce emission further.
Corporate	• Understand the linkage in value chain. • Line of sight from operational to corporate KPIs. • DTw / CPS becomes a financial asset in addition to the physical asset
Other stages - Design, Build Dispose *(stages not covered in this paper but noted for future reference)*	• Improved design - test virtual model for reduced emissions compared to historical data – (Metallidou, 2022 and Agdalla (nd)) • Reduced re-work in build stage. • Enhanced safety during build stage • Identified material for recycling at disposal stage.

Thinking further about the system feedback and re-enforcing loops, Figures 7 and 8 demonstrates how data flows can create impacts. Figure 7 shows how data allows operating decisions which can reduce carbon emissions by ensuring the asset is operating efficiently within specifications.

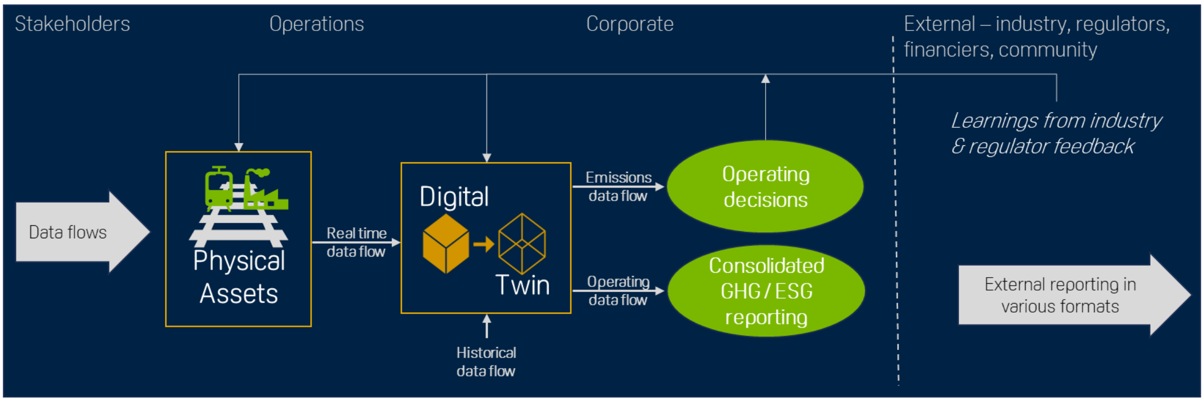

Figure 7. Feedback loops across carbon system.

In addition, across the reporting chain industry groups are seeking to understand how the industry is performing and publicising and promoting good practices which can be adopted by other industry players. As an example, the M5 East tunnel in Sydney faces air quality issues due to its HVAC system's varying performance under different conditions, such as vehicle numbers and speeds. This indicates a direct correlation between system efficiency and carbon emissions (O'Sullivan, 2018). Implementing a CPS could significantly enhance sustainability and optimise the tunnel's environment.

Figure 8 show data flowing upwards through various layers of the organisation to enable efficiency gains, as well as accurate and transparent reporting of carbon emissions. Accurate data reporting from a DTw / CPS solution allows informed operating decisions which is not feasible when the data is estimated and not regarded with the same validity. From an organisational perspective there is not only reduction in operating costs, but the potential for new revenue gains through additional sources – an example of this would be a DTw/CPS in a processing facility streamlines costs and saves time with automated emissions reporting and asset performance optimisation. It also boosts revenue by providing detailed traceability and transparency, thus validating the facility's environmental sustainability and green credentials.

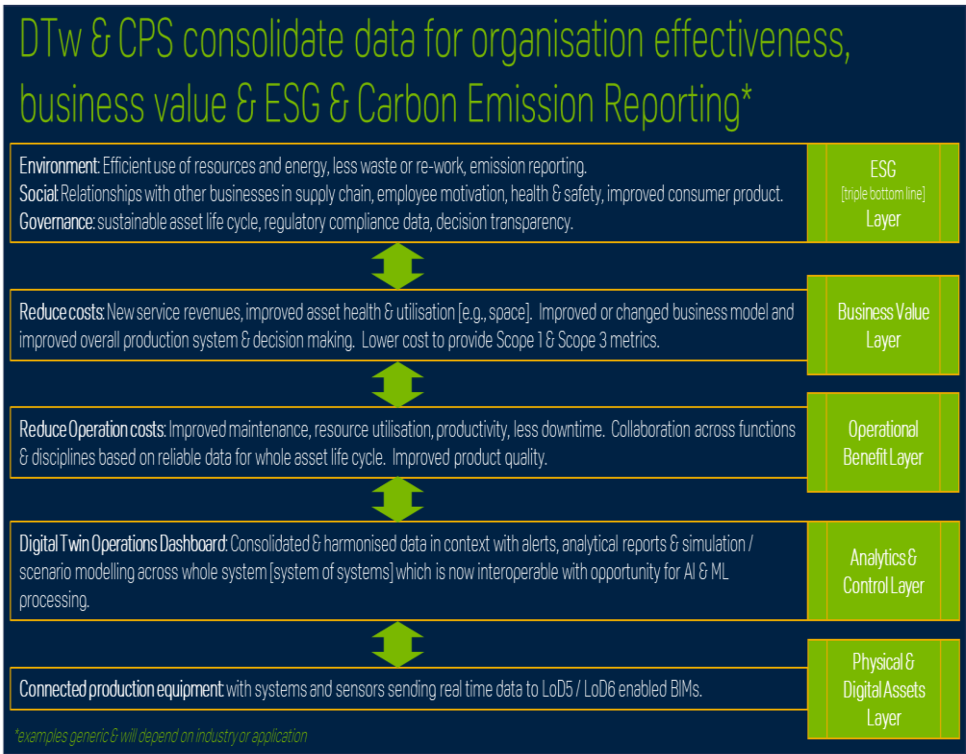

Figure 8. Carbon data flow across organisational layers.

Discussion & Conclusion

Politically and economically, this is an appropriate time to start planning for an initial digital twin that can provide both carbon emissions reporting as well as operational productivity gains, starting with a minimum viable product (MVP) that allows you to start quickly, examine results and then build on and extend the MVP. It will also allow you to strategise, plan and create a roadmap for future connected digital twin applications in a cyber physical system and a robust business case to support the ongoing investment.

There will soon be more government mandates on carbon reporting which require greater levels of transparency and validity and organisations that have digital twins and cyber physical systems will be able to easily comply and not be in reactive mode.

For example - On 26 June 2023, the International Sustainability Standards Board ('ISSB') released its inaugural global sustainability reporting standards, IFRS S1 and IFRS S21 ('Standards'). Australian companies must proactively prepare for these forthcoming changes, with mandatory climate-related financial disclosure anticipated to impact our shores as early as Quarter 2 2024 as the Standards are adapted for the Australian context.

Once you have established the MVP and the roadmap this will also be effective publicity for shareholders and stakeholders, to demonstrate alignment with the organisation's corporate social responsibility goals. The MVP will also enable the organisation to start the process of changing mindsets internally and externally and especially that carbon reporting using digital technology can be changed from an overhead to an economic enhancement and competitive advantage and also deliver benefits for operational efficiency and productivity.

It is clear from surveys that organisations are increasingly investing in this technology, as noted in the Capgemini (2022) report:

> *"According to the 'Digital Twins: Adding Intelligence to the Real World' report from the Capgemini Research Institute, 60% of organizations across major sectors are leaning on digital twins as a catalyst to not only improve operational performance, but also to fulfil their sustainability agenda. By being able to simulate the physical world, digital twins can help organizations to better utilize resources, reduce carbon emissions, optimize supply and transportation networks, as well as increase employee safety."*

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