Systems Approach to an Evolved Nuclear Sector Deal and Net-Zero

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August 2021

Introduction

The context for this work is consideration of the whole system to identify aspects that may be changed to achieve the goal of nuclear making an effective and efficient contribution to net-zero in the UK.

To support the development of an evolved Nuclear Sector Deal, a high-level systems analysis has been carried out of the nuclear enterprise, through which more detailed work can be identified for further investigation. The focus is human activity systems, i.e., those systems of an organisational nature within a socio-technical context; the analysis does not consider the scientific or engineering aspects of the nuclear sector, except for their influence on the organisational systems. A Soft Systems Methodology (SSM) approach has been applied, loosely based on the methodology developed by Checkland[1]; to identify relationships between the various parts of the enterprise[i] from which issues have been identified by sector experts.

The issues identified can inform the evolution of the Nuclear Sector Deal.

Brief details of the SSM upon which this analysis is based are provided in Appendix A.

Data Gathering

Application of SSM

The systems model presented is based on the output of two expert stakeholder workshops held two-weeks apart. In the first, relevant systems were identified based the transformation the systems are supposed to achieve, the participants in the system, and the context. The Soft-Systems Methodology (SSM) should try to capture all worldviews of a situation, i.e., explore it from many perspectives, but the constituency for the workshops was entirely from the nuclear sector (including Government, industry, and NGOs). It is fully appreciated that there are other views not represented in the data collected.

The second workshop took the form of a brainstorm session in which the systems identified in workshop 1 were first validated and then problems and opportunities associated with them were identified.

The participants in the workshop were associated with the organisations listed in Appendix B.

Both workshops were conducted using Microsoft Teams, rather than the more usual format of working around a physical whiteboard.

Outputs from Workshops

Summary of workshop outputs

The output of workshop 1 was a map of systems included in the nuclear enterprise clustered into nine themes. The output of workshop 2 was an elaboration of the map of systems and identification of issues to be addressed. The workshop outputs are transitional information leading to the systems model in section D; they are included in Appendix C for information.

[i] An Enterprise is a group of organisations working together to achieve a particular outcome or to maintain a capability

Causal Loop Diagram (CLD)

How a CLD works

A CLD is a diagram based on simple rules that specify relationships between different quantities. The relationships are simply between to quantities (A and B) so that the either increase/decrease in the same (S) way (e.g. A goes up leads to B going up) or in the opposite (O) way (i.e. A goes up leads to B going down). Examples from Figure 1 are Same: an increase in nuclear generation capacity leads to an increase in total electricity capacity (all sources), or Opposite: an increase in Total electricity capacity (all sources) leads to a decrease in the projected energy shortfall and vice versa. The CLD can become quite complicated as more entities are added. It should reflect all the interdependencies and will reveal feedback loops in the system, which may be reinforcing (R), i.e., growing, or balancing (B) i.e., decreasing.

Causal Loop Diagram of Nuclear Enterprise

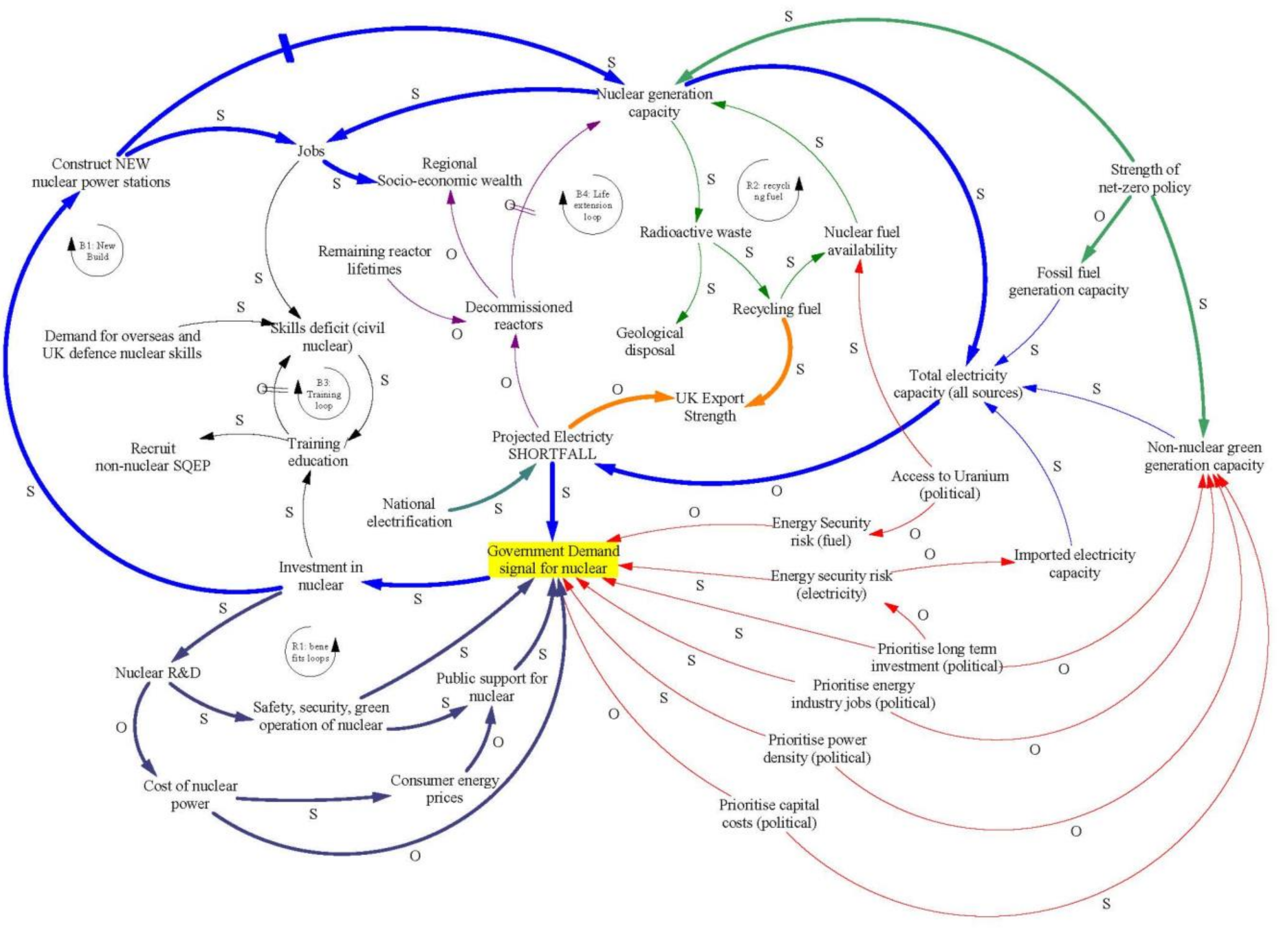

Figure 1: Causal Loop diagram for meeting energy needs through nuclear power: S=quantity at arrowhead increases or decreases in same direction as quantity at the root; O=opposite. Double bar on arrow indicates (substantial) delay. B=balancing loop, R=reinforcing

The relationships in Figure 1 and their implications are described below; the associated relationships are clustered by colour (noted to the left of the relevant paragraphs).

Net-zero assumption

Net-Zero policy is an underpinning assumption for the model in Figure 1, the more vigorously this is pursued, the more generation capacity is switched away from fossil fuels to green alternatives that include nuclear, renewables, hydropower, hydrogen recovery, etc.

Increasing electricity demands

Electricity demand is likely to increase[2], due to many factors, such as:

- Electrification of transport (e.g., electric cars)
- Electrification of heating (gas replacement by 2025)
- Increase use of digital devices (e.g., comms)

As electrification increases, so the projected shortfall increases (until new generation is added).

Criticality of Govt. demand signal for investment

The Government demand signal is critical with respect to growth or decline of the nuclear sector: Investment will only happen if there is a positive signal.

- Permission to site a nuclear facility is a Government decision; note that this may form a key part of the levelling up agenda in terms of regional investment
- Investment by energy companies is triggered by the Government demand signal
- Investment by non-sector stakeholders (e.g. digital industries) is triggered by the Government demand signal
- Acceptability of investment (particularly overseas investment) is determined by Government
- For largescale facilities, Government financial investment is needed to de-risk private investment; for small scale (e.g. Small Modular Reactors – SMR) the demand signal, which is effectively a guarantee, may be sufficient to trigger private investment.

Factors influencing Govt. demand signal

The projected electricity shortfall motivates positive signals for nuclear development, but the following factors influence the balance between nuclear and non-nuclear green options:

- Energy security: anticipated growth in energy demands, the decommissioning of older reactors, the net-zero target, and a changing international political environment affect the risk to energy security. If political assessment of energy security risk increases, then reliance on imported electricity is diminished and the signal for nuclear energy is increased.
- Broadly, a new nuclear reactor may be operational for 80-100 years, whereas alternative green energy sources require replacement on an approximately 20-year cycle. Therefore, long-term investment (and associated energy security) will strengthen the demand signal for nuclear.
- The nuclear energy supply chain generates more employment than other green sources (such as wind power or solar panels), therefore, prioritising jobs (particularly as a component of levelling-up) would strengthen the demand signal for nuclear.
- Power density (i.e. electrical power produced per horizontal m^2 of surface area) of nuclear is more 40 times higher than solar and more than 100 times higher than wind power[3]; thus prioritising efficient land use would strengthen the demand signal for nuclear.
- Public support for nuclear power is a factor in the political decision of the Government Demand signal; this is influenced by many factors including cost of energy, perceptions of safety, security, and environmental impact.
- The economic case is the most significant factor of all. Cost is an over-simplification in the model of Figure 1. based on a simple consideration of capital cost of facilities etc., the argument for nuclear is diminished, but on a wider consideration of the value and opposite conclusion may be reached.

Cost and value consider-ations

Considering the Levelised Cost of Electricity (LCOE) the International Energy (IEA) and the OECD Nuclear Energy Agency (NEA) concluded that Long-Term Operation (LTO) of nuclear energy represented the best value, despite reductions in the costs of various renewable energy options[4]. However, there are many complicated considerations that influence the outcomes of analysis. In the case of the UK, there are seasonal and regional differences in value. Very importantly, the IEA analysis considers systems factors, such as integration into the grid, the relative changes in value according to level of penetration of renewables (basically, as penetration increases the relative value decreases), and the storage costs for energy for non-continuous generation. But the cost of construction is currently high for new nuclear plant, and so achieving cost reduction is also an important factor.

Decommissioning old reactors

Most current UK reactors are approaching end of life and decommissioning is either underway or expected shortly[5]. The growing demand for electricity drives the Life extension loop (Balancing loop B4).

- The number of decommissioned reactors reduces generation capacity, but projected shortfall effectively delays the decommissioning. This maintains the nuclear generation capacity for a limited time determined by the remaining lifetime for safe and efficient operation.
- It should be noted (not shown in Figure 1) that the decommissioning activity itself generates jobs.
- But decommissioned reactors may cause a reduction in regional socio-economic wealth, as jobs are lost are lost from the area and investment may be diminished. Without action, this may run counter to the levelling up agenda.

New construction

The Government demand signal begins the process of construction of additional nuclear facilities – which can be viewed as replacements for decommissioned reactors or expansion of the nuclear generation capacity.

- New construction creates new jobs both in the region where the nuclear facility is to be sited and in the supply chain more generally, which includes construction sector.
- Depending on the type of reactor, nuclear generation capacity is increased after a delay of about 10 years, or 5 years if SMR is considered.
- New generation capacity also leads to the creation of new jobs supporting the regional economy.
- There is a new build balancing loop (B1) that begins with the Government demand signal in response to the projected electricity shortfall and eventually increases nuclear generation and thence total electricity capacity. This reduces the shortfall, so that the strength of the Government demand signal reduces.

Skills demand

Construction and the resulting expansion of the nuclear contribution to electricity generation will create a skills deficit that must be addressed. The approaches to acquiring the necessary skills are likely determined by timescale: there will be a need for a relatively short-term nuclearisation of existing construction skills and a need for long-term development of nuclear professionals.

- Investment in nuclear should support training and education in required skills: there may be a time lag in acquiring sufficient skills to meet demand.
- Training may include graduates and also sufficiently qualified and experienced people from non-nuclear industries being retrained to support nuclear expansion.
- Over time the training loop is potentially balancing (B3) because once the skills deficit is met, the need diminishes, and the amount of training may reduce.
- The skills deficit can also be addressed by recruitment from UK defence nuclear, but this is also expected to expand creating a competition for skilled workers. Given potential for competition for these skills, it would make sense for civilian and defence nuclear sectors to jointly plan and invest in the expansion of these skills.
- Similarly, recruitment of skills from overseas is possible – assuming an appropriate immigration policy – but skills can also be lost to support overseas nuclear sector.

R&D benefits loop

Research and Development may affect many aspects, from incremental improvements to current technologies to the introduction of new technologies (e.g. fusion) into mainstream electricity generation.

- R&D enhances safety, security, net-zero achievement, and cost; all of which increase Government confidence in nuclear through a reinforcing loop (R1).
- The same enhancements influence public support for nuclear generation, particularly reductions in consumer price for green energy.

Radioactive waste management

Increased nuclear power generation (and also decommissioning activities) give rise to increases in radioactive waste.

- A small proportion of waste must be disposed of geologically.
- Geological disposal generally has a negative impact on public support (not shown in Figure 1). However, it is important to note that the community that hosts the Geological Disposal Facility (GDF) benefits from increased employment that may be regarded positively.
- Some fuel can be processed for recycling.

Nuclear fuel availability

The increase in nuclear generation requires access to nuclear fuel.

- UK must import mined fuel, and this poses an energy security risk (fuel), which diminishes the strength of the Government demand signal for nuclear (i.e. opposite effect to the risk for imported electricity). However, fuel is also available from recycling of tailings and from weapon decommissioning.

Export

The UK has export potential with respect to nuclear power.

- When total generation exceeds demand (i.e., shortfall becomes negative) then the UK has the potential to export electricity.
- Expertise in recycling nuclear waste is an export opportunity.

Relationships between, and key issues for, the human activity systems that comprise the nuclear enterprise

Abstract model of the nuclear enterprise

Figure 2shows the various complex dependences between the human activity systems (HAS) and allows one to trace the implications of changes to a particular HAS through the system as a whole. In *Figure 2*, we identify sixteen abstract HAS associated with the enterprise. In each case, they represent a set of real systems that deliver the high-level functionality indicated. We use this model to identify areas where improvements are needed to increase the benefits of nuclear power, with the goal of nuclear making an effective and efficient contribution to net-zero in the UK.

The areas for improvement are listed below as issues associated with each system, although some span several systems.

a. Demand signal

A system to generate demand signal from Government: all development relies on this signal that enables new build to begin (with guarantees) and without which investment will not be committed. Motivations for Government to signal are the growing gap between generation and power demand, the need to eradicate fossil fuel generation, the inadequacy of renewable energy sources to meet the future need, and long-term energy security. Disincentives to signal are insufficient public support, significant upfront investment, and failure to recognise the green contribution from nuclear.

Issue a1: long lead times for new build require the signal to be given approximately ten years before need.

b. Investment

A System to generate finance for new schemes: If the Government demand signal is given, then investment opportunities arise. Costs for new AGR/PWR are measured in £billions, so joint funding between Government and industry is required. SMRs offer lower cost nuclear power in which industry may invest independently. Permitted investors are determined by Government. Potential investors now include non-energy companies whose products drive the need to increased electricity generation (digital technologies, electric vehicles, etc.)

Issue b1: long-term clarity on permitted investors (subject to changing FCO policy)

Issue b2: rapid development and implementation of SMR to encourage investment

Relationship Diagram of Nuclear Enterprise

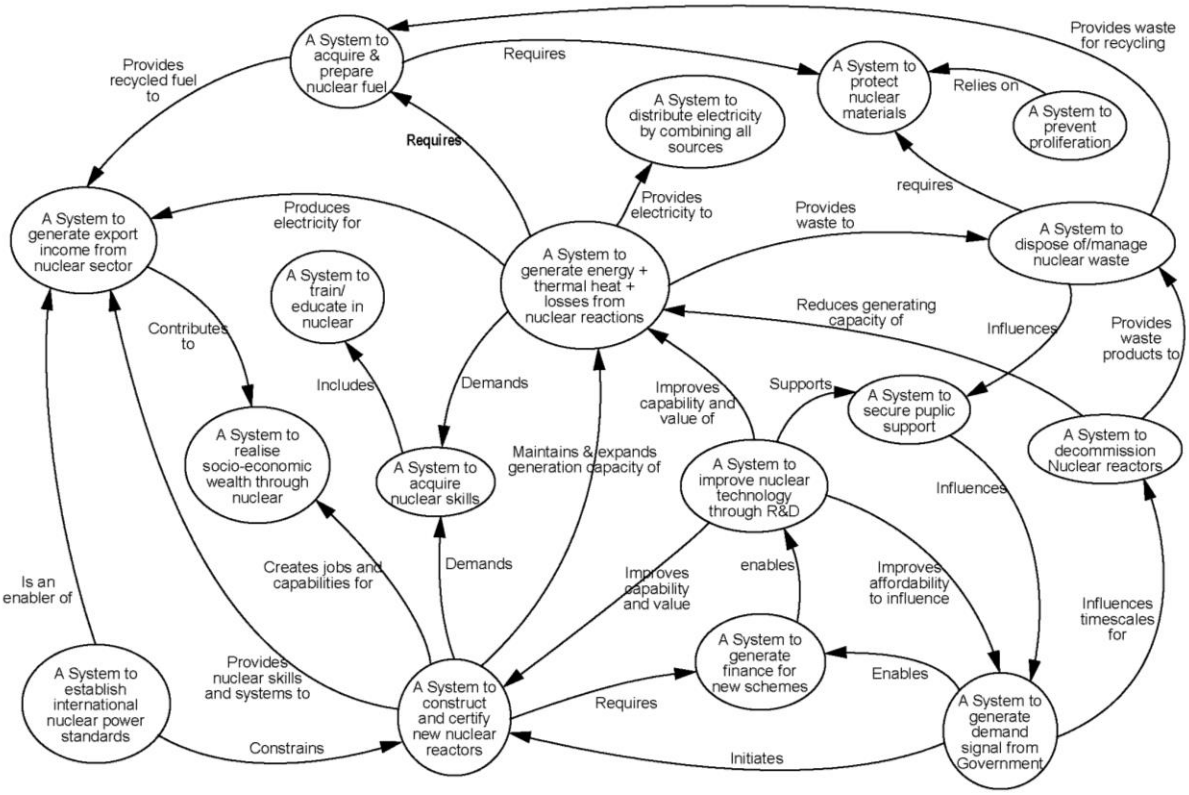

Figure 2: Human activity systems associated with the nuclear enterprise

c. New build

System to construct and certify new nuclear reactors: A complex enterprise to plan, design, and build new reactors. Certification of new types requires work between industry and regulators to establish practice.

Issue c1: skills deficit could hold up construction

Issue c2: long construction times

Issue c3: certification readiness for SMR

d. Skills deficit

System to acquire nuclear skills: in fact, a broad range of needed skills from welding to reactor design are in short supply. Acquisition of the needed skills includes training new people and recruitment from other nuclear employers, such as defence and overseas.

Issue d1: defence also needs additional skills: there should be co-ordination to work collaboratively on skills acquisition

Issue d2: current structures and available training inadequate to meet demand

Issue d3: competition with other nuclear industries for scarce skills

e. Training

System to train/ educate in nuclear skills: sub-system of system to acquire nuclear skills, this system includes university education in nuclear energy and transformation of SQEP from other sectors into nuclear energy trained workers. The system must also rapidly train workers in more general nuclear construction skills to meet the demands of new build.

> **Issue e1:** insufficient capacity to meet needs of nuclear industry in next ten years

f. Combined cycle power plant

System to generate energy + thermal heat + losses from nuclear reactions: In addition to generating electricity, nuclear power plants also generate thermal heat that may be exploited in other industrial processes or stored for later use. Energy losses from nuclear power are comparatively small. Although this is the technical system for generating energy it is included in this model because of its significance in terms of fully exploiting the energy from a green energy perspective.

> **Issue f1:** thermal heat is inadequately exploited at present

g. Balancing distribution

System to distribute electricity by combining all sources: required to balance electricity supply with demand due to intermittent nature of some renewable sources. Includes import of electricity (particularly for managing surge). Nuclear provides a baseline source.

> **Issue g1:** Imported electricity represents a risk to capacity due to political dependency

h. Fuel

System to acquire and prepare nuclear fuel: The system includes import of uranium from countries with natural deposits, refinement, enrichment, reprocessing, and transportation. The UK is dependent on other Uranium rich nations for supply but has significant capability in enrichment and reprocessing. The latter are export opportunities.

> **Issue h1:** Dependence on other nations for uranium sources

j. Export

System to generate export income from nuclear sector: Export system includes electricity, skills, technology, complete systems. Export only possible with Government permission. SMR represents new opportunity for export.

> **Issue j1:** UK projected demand imply net importer of electricity

> **Issue j2:** Education system lacks capacity for skills export

> **Issue j3:** Skills and whole system experience is not competitive in export market

k. Standards

System to establish international nuclear power standards: System owned by ISO to ensure interoperability of nuclear technologies and consistent safety regulation.

> **Issue k1:** interoperability standards needed to enable export of technologies

l. Security

System to protect nuclear materials: The system ensures security of fissile material: confidence in this system is essential for public confidence in the nuclear industry.

m. Disposal

System to dispose of/manage nuclear waste: The system includes treatment, packaging, storage, disposal, and monitoring.

n. Decommissioning

System to decommission nuclear reactors: The system dismantles structures, decontaminates the facility and site, removes contaminated materials for processing and storage, and restores the site for other uses.

Issue n1: Decommissioning is a costly system to operate

Issue n2: life extensions needed to meet projected electricity shortfall: gap between decommissioning and replacement capability

Issue n3: adverse economic impact on local area due to loss of jobs etc.

p. R&D

System to improve nuclear technology through R&D: The system includes management of technology from concept to implementation.

Issue p1: certification of new technologies (time and cost)

Issue p2: “valley of death” loss of opportunity during TRLs 5-7

q. Public support

System to secure public support for nuclear: The system informs public understanding and makes the case for investment in nuclear power.

Issue q1: lack of appreciation of nuclear as a green option

Issue q2: Chernobyl and Fukushima: trust in safety of industry

Issue q3: lack of co-ordination between nuclear stakeholders

r. Levelling up

System to realise socio-economic wealth through nuclear: The system forms a part of the levelling up agenda and concerns investment in, and development of local infrastructure to support nuclear facilities. In terms of decommissioned facilities, this system provides replacement employment and infrastructure for continued socio-economic wealth in the local area.

Issue r1: financial and social planning for transition following decommissioning

s. Whole system

Overall Nuclear Activity System: The system that links all the above systems.

Issue s1: Interoperability across the whole system

Issue s2: knowledge sharing between organisations within the whole system enterprise

Summary and Some Initial Conclusions

The most critical system in terms of realising the potential of nuclear to effectively and efficiently contribute to net-zero is the Government Demand Signal: without this no expansion of nuclear contribution can take place and replacement of existing facilities cannot occur. Significantly, failure to issue the demand signal in a timely fashion could lead to a significant electricity deficit, just at the time when electricity usage is likely to massively increase. The demand signal is influenced by:

- UK net-zero aspirations
- Projected electricity deficit
- Energy security considerations (political influences on fuel availability and electricity imports)
- Long-term value compared to renewable energy sources: the estimate of value requires agreement about priorities and assumptions among all stakeholders.
- Employment
- Power density

Twenty-seven issues have been identified through the analysis, summarised in Table 1. This report does not provide solutions to these issues but is intended to highlight them as areas for attention by the nuclear sector in order to achieve the **goal of nuclear making an effective and efficient contribution to net-zero in the UK**. Based on the identification of issues, the workshop participants prioritised the following five areas with some additional suggestions for solving the issues:

- A system to generate demand signal from government. Due to long lead times for new build, delays in this signal increases the risk on an energy generation deficit. Everything is dependent upon it: initiation of new projects, the investor confidence to support new projects, and development of more effective nuclear technologies. In fact, its criticality means that the signal must be given even before the cost and performance of potential alternatives have been proved. Although this also influences life extensions for existing reactors, this provides only short-term relief.

- A system to acquire nuclear skills. In fact, it is both construction skills for new build and nuclear expertise of operation of new reactors that are in short supply. This deficit can be made up through recruitment of overseas expertise, retraining of suitable staff from other industries, or through enhancing graduate and apprenticeship opportunities in relevant subjects. It is noted that there is a simultaneous increased demand from the defence nuclear sector and effective collaboration on skills between civilian and defence nuclear industries is essential.

- A system to generate finance for new schemes. The ability to raise finance at the lowest cost of capital requires clarity from Government on permitted investors, so that the deep pool of infrastructure investors can be accessed with an appropriately structured package based on the regulated asset base model.

- A system to improve nuclear technology through R&D. Investment in research, development and certification practices is essential to ensure lower cost systems that can be more rapidly developed and transitioned to operation. Consideration should be given to open architectures as a means through which agility may be achieved. A change in the model for generation that exploits Small Modular Reactor (currently under development) technologies would reduce the time and cost of deployment, which may alleviate an impending energy deficit.

- A system to generate export income from the nuclear sector. The UK has significant capabilities in nuclear power and, with expansion in the future, possibly the ability to generate surplus electricity. These provide a significant export opportunity. The establishment of appropriate international commercial standards is an enabler for export; but to achieve this the UK must be a leader in establishing standards.

Table 1: Summary of Issues for an evolved Nuclear Sector Deal and Net-Zero

Issue a1:	long lead times for new build require the signal to be given approximately ten years before need.
Issue b1:	long-term clarity on permitted investors (subject to changing FCO policy)

Issue b2:	rapid development and implementation of SMR to encourage investment
Issue c1:	skills deficit could hold up construction
Issue c2:	long construction times
Issue c3:	certification readiness for SMR
Issue d1:	defence also needs additional skills: there should be co-ordination to work collaboratively on skills acquisition
Issue d2:	current structures and available training inadequate to meet demand
Issue d3:	competition with other nuclear industries for scarce skills
Issue e1:	insufficient capacity to meet needs of nuclear industry in next ten years
Issue g1:	Imported electricity represents a risk to capacity due to political dependency
Issue h1:	Dependence on other nations for uranium sources
Issue j1:	UK projected demand imply net importer of electricity
Issue j2:	Education system lacks capacity for skills export
Issue j3:	Skills and whole system experience is not competitive in export market
Issue k1:	interoperability standards needed to enable export of technologies
Issue n1:	Decommissioning is a costly system to operate
Issue n2:	life extensions needed to meet projected electricity shortfall: gap between decommissioning and replacement capability
Issue n3:	adverse economic impact on local area due to loss of jobs etc.
Issue p1:	certification of new technologies (time and cost)
Issue p2:	"valley of death" loss of opportunity during TRLs 5-7
Issue q1:	lack of appreciation of nuclear as a green option
Issue q2:	Chernobyl and Fukushima: trust in safety of industry
Issue q3:	lack of co-ordination between nuclear stakeholders
Issue r1:	financial and social planning for transition following decommissioning
Issue s1:	Interoperability across the whole system
Issue s2:	knowledge sharing between organisations within the whole system enterprise

References

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2. National Grid. *Future Energy Scenarios Navigation*. (2020).

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Acknowledgement

We are grateful to Drs Sheryl Williams, Chuka Nwabunike, Tendai Dube, and Melanie King of Loughborough University for workshop support.

Appendix A: Briefing Note to Workshop Participants, including explanation of Soft Systems Methodology

Systems Approach to Nuclear Sector Deal and Net-Zero - Briefing for Participants

Prof. Michael Henshaw, Loughborough University

As part of the initiative to update the Nuclear Sector Deal, a work package is introduced to use a Systems Thinking activity to inform planning. A "Systems Approach" may be used for hard (purely technical) or soft (human + technical) systems; in this case, we use a Soft Systems Methodology (SSM) to consider the nuclear power enterprise for the purpose of identifying areas of the whole system that may be changed to achieve the **goal of nuclear making an effective, efficient, and efficacious contribution to net-zero in the UK**.

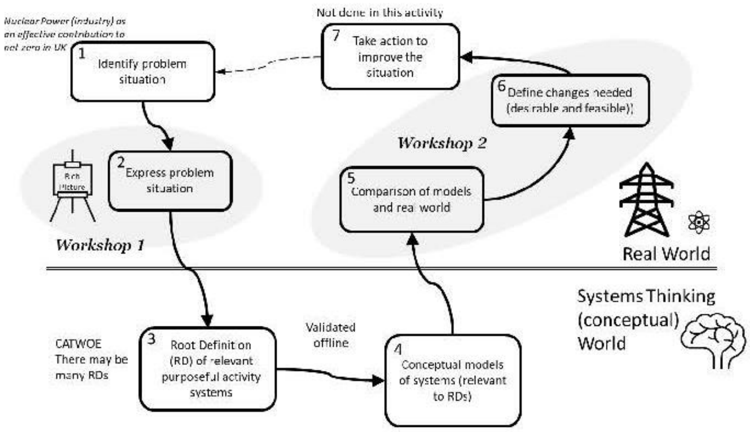
SSM is widely used in industry: it was developed by Peter Checkland and co-workers in the 1970s out of a recognition that the (deterministic) techniques used for hard systems were inadequate for situations involving human activities. Such systems are "messy", partly because different stakeholders may view the same situation differently and behave accordingly.

SSM seeks to capture the different views within a model so that different perspectives may be appreciated by all and solutions developed that may be fully adopted and implemented. It recognises the complexity of human activity systems and seeks solutions from an holistic perspective.

Worldviews
Aerospace Engineer: problem of blade design, Civil Engineer: structures and site design, Grid Operator: electricity supply and commercial arrangement, Neighbour: blot on the landscape,...

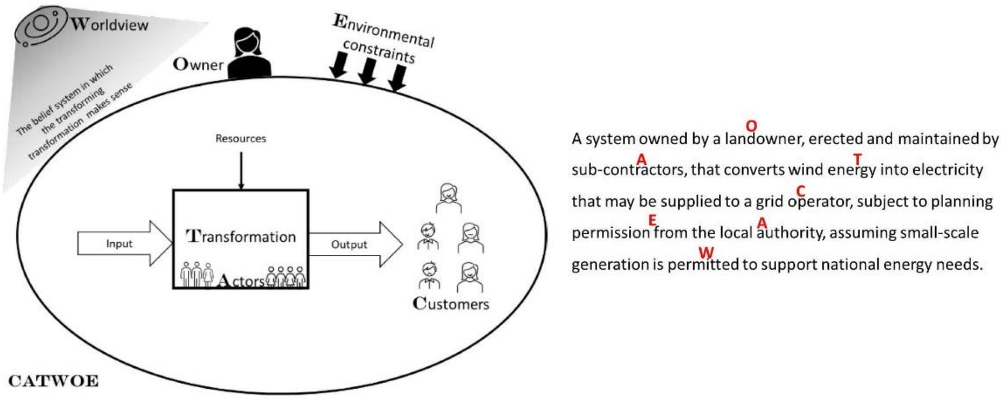
The time to conduct this study is much less than is usually available; our ambition will, then, be to capture as many perspectives as possible and identify areas for improvement at a high level.

The SSM Process is shown below. 1. We have already identified the "problem" as the challenge of making nuclear an effective contributor to the UK net-zero target, where "effective" takes into account long-term commercial, environmental, and whole-industry considerations. 2. We shall workshop the different perspectives and the variety of system involved. A technique of rich pictures (collaboratively sketching out entities and relationships) is used. This is going to be challenging in an online environment come along prepared to experiment a bit in how to convey your ideas. 3. The systems involved will be defined by a Root Definition (RD): this has a specific form and is used to precisely define the system (see below). We shall iterate these definitions offline to save time. 4. From the RDs, conceptual models will be constructed that we shall seek to validate offline. In a sense, these simple models will describe how we think the systems should work ideally. 5. Your expertise will be used to identify the gap between the ideal



and current reality in the second workshop. From there we can identify together 6. what changes are needed. There is no restriction on the extent of these changes: they may be short-term easy fixes, or massive long-term ambitions, we shall try to capture them all. We shall not carry out 7. (implementation) because our purpose is to feed the findings into the refreshed nuclear sector deal.

A Word about Root Definitions. Checkland introduced a mnemonic, CATWOE, to define the components of a RD. All Systems Transform an input into an output, we must be clear for each system what the input and output are: keep in mind the input is what is transformed into the output, not necessarily the resources needed for the transformation (e.g. the wind turbine transforms wind kinetic energy into electric energy, the oil used to grease the components is not transformed). The output is received by Customers: these could be beneficiaries or victims. There are Actors who are active in the transformation (sometimes Customers may also be Actors, but not necessarily). The system under consideration is subject to Environmental constraints: we must briefly describe the environment in which the system can operate (e.g. increased Government investment, or a windy area). The system has an Owner: the easiest way to identify the owner is to ask the question "who could stop the transformation?". Lastly, there is the Worldview in which the transformation makes sense. Peter Checkland used the word *Weltanschauung* unfortunately! An simplified example of a RD is given below (note that although the local authority could stop installation, once permission is granted this becomes part of the environment, so it is arguable whether they continue as actors).



For **more information** on SSM, I recommend Checkland P and Scholes J, "Soft Systems Methodology in Action", Wiley, Chichester, 1999.

The **Workshops** will be challenge using MSTeams, however, we have managed these types of events previously using online resources and will provide instructions on the day to enable you to interact effectively. It is very important that we all fully understand each other during the workshop, and so I do request that you avoid interruptions that will distract you from full attention.

Open Architectures is concerned with the way that we integrate (or more correctly interoperate) systems that may be developed and operated by different organisations. It is a topic of both technical and commercial relevance. Work we have conducted in the defence sector has shown the benefits in terms of commercial, operational, and technical agility. I will present that work and outline how it may be worth consideration as an enabler of the nuclear sector ambitions.

Michael Henshaw, 7th April 2021

Appendix B: Workshop Participants – organisations represented

Atkins (1)

AWE (2)

EDF (1)

Jacobs (1)

Loughborough University (1)

Lucid Catalyst (1)

National Nuclear Laboratory (NNL) (1)

Nuclear Advanced Manufacturing Research Centre (NAMRC) (1)

Nuclear Decommissioning Authority (NDA) (1)

Nuclear Industries Association (NIA) (1)

Nuclear Sector Deal (NSD) Programme Management Organisation (3)

Nuclear Skills Strategy Group (NSSG) (1)

Office for Nuclear Regulation (ONR) (1)

World Nuclear Association (WNA) (1)

UK Ministry of Defence (MoD) (1)

Urenco (1)

Westinghouse (1)

Young Generation Network (YGN) - Nuclear Institute (1)

Appendix C: Outputs of the Workshops

The outputs from workshop 1 were captured on a map of systems shown in Figure 3 and grouped into nine clusters. The systems are described as transformations, listed in Table 2.

Following validation of workshop 1 systems, the map was annotated in workshop 2 and based on this a list of issues was identified. The annotated map is shown in Figure 4.

Figure 3: Map of systems associated with the nuclear enterprise created by combining the outputs of three groups at Workshop 1

Table 2: Systems identified by the transformation they perform; this table accompanies Figure 3

Theme		Transformation achieved by the system in question
Whole electricity distribution system	T01	Electricity generated through any source is transformed into electricity for distribution to all electricity consumers
Affordable nuclear energy	T02	Expensive nuclear energy solutions transformed into low-cost nuclear energy solutions
	T03	Inadequate funding is transformed into adequate funding for nuclear projects
	T04	Money from sale of electricity to current consumers is transformed into funding for future nuclear systems
	T05	Nuclear fuel is transformed into electric power + thermal energy + heat loss

Improvements in deploying technology	T06	Prototype advanced reactors and new models transformed into deployed nuclear systems
	T07	Research in nuclear energy (efficiency, safety, materials, data and decision toolkits) is transformed into deployable systems
	T08	Unlicensed technology is transformed into licensed technology for nuclear power generation
Export	T09	UK skills, knowledge, products, systems, materials are transformed into export income
Waste management	T10	Untreated nuclear waste is transformed into safely buried nuclear waste
	T11	Nuclear waste is transformed into medical isotopes
Security	T15	Unprotected radioactive materials are transformed into protected radioactive materials
Workforce	T12	Nuclear-skilled workers are exchanged between civil and defence sectors
	T13	Suitably qualified and experience people in non-nuclear industries are transited into the nuclear industry
	T14	Non-UK nuclear and non-nuclear workers are transited into UK nuclear industry
Public perceptions	T16	Sceptical public are transformed into nuclear-positive public
Regeneration	T17	An economically deprived area is transformed into a thriving economic area
Decommissioning		These two themes added at workshop 2
Government Demand Signal		

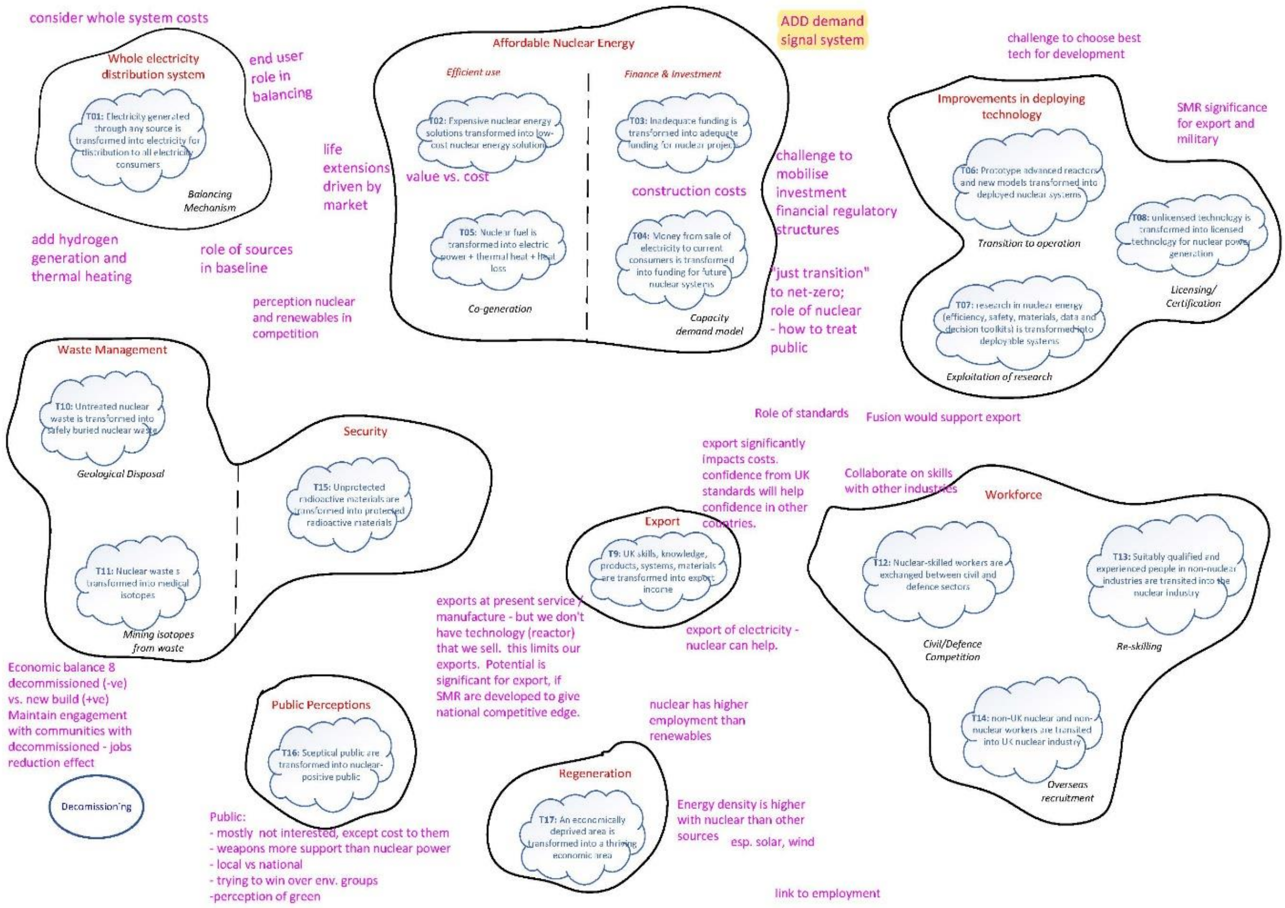


Figure 4: Map of Systems with notes added during workshop 2