THE RESOURCE SUPPLY SYSTEM

COMPONENTS, STRUCTURE, DYNAMICS

David C. Elliott, Ph.D., F.G.S.

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SUMMARY

All life relies on the resources of the earth. From the long ago use of obsidian and flint for cutting and scraping, to the current demand for rare earth elements, the growth in the use of the type and quantity of resources from the earth has shaped our present society and economy. Without an adequate supply of these resources, our current society would not continue in its' present form. Extraction and use of resources have effects on the environment and on all life forms that can never be fully eliminated or reversed.

The behaviour of individual resource supply projects is usually reasonably well understood. This is not the case for the supply that comes from an aggregate of many individual projects, a Resource Supply System (RSS) that forms a dynamic complex system with many crosslinks and dependencies. The response to changes in such a system is typically non-linear and often unpredictable, which presents significant challenges for the management of resource supply.

The objective of this paper is to provide information on the fundamental components (elements) and structure of an RSS as a basis for further work. The starting point of an RSS is the recognition of a demand, leading to identification of sources, such as ore bodies or a site suitable for a windfarm, and it then passes through the physical procedure of recovery, processing, and transport, to a supply to a user. To progress successfully, it must attract adequate financing, and satisfy constantly changing background conditions of economic, legal, regulatory, social, and environmental viability, etc. All of these conditions must be satisfied before a resource can be delivered to a user.

It is divided into the follow parts:

A: THE RESOURCE SUPPLY SYSTEM, Sections 1 to 6, Introductory material.
B: ELEMENTS OF THE RESOURCE SUPPLY SYSTEM, Sections 7 to 12 describe the fundamental elements ("bones") of an RSS.
C: CONCEPTS, Sections 13 to 15 describe concepts, such as valuation, uncertainty of information, contingencies, and decision rules, that underlie resource supply.
D: COMMUNICATION, Section 16.
E: THE STRUCTURE AND DYNAMICS OF THE RESOURCE SUPPLY SYSTEM, Section 17, describes how the elements and concepts may be used to represent resource supply as a system (using the "bones" to construct a "skeleton").
F: APPLICATIONS, Section 18. No attempt has been made to develop the full scope of applications of the RSS model is provided here but there is a brief description of some potential uses.

The focus is not on any specific resource type and its applications will depend on the purpose of a study. It not limited to the UN Expert Group on Resource Management (EGRM) or the resources currently covered by the United Nations Framework Classification system.

Compiling a report on a topic of this scope presents a challenge as to the amount of detail to include, since each section could easily be expanded to book size. The report is intended to provide only an overview of the RSS for a variety of users, including those with only a limited knowledge of the industry. References provide access to more complete information for an interested reader, and considerable information is also available in public sources.

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David C. Elliott
davide5@telus.net
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PART A: THE RESOURCE SUPPLY SYSTEM

Following an introduction, Part A covers general aspects of resource supply, including: the need for a defined terminology, the concept of a "Realm of Discourse" (ROD), the questions of what is a "natural resource" and how resource supply may be "managed" as a system that contains many individual projects.

1. INTRODUCTION

Our society relies on the supply of many types of resource: metals, oil and gas, coal, electricity, water, etc. Resource management is an active process that attempts to provide the timely and efficient supply of a required resource to users. A prerequisite to managing resource supply is an understanding of the structure of a Resource Supply System (RSS), an aggregate of many individual projects. It is a subset of a much larger Human World Economic System (HWES)[1] that is not addressed here except for limited comment, to provide context.

The basic elements of a resource supply system include:

- A demand, indicating a market.
- Identification of sources.
- Entitlement, the right to recover and market a product from a source.
- A physical system to produce, process, and transport a resource to a user.
- Financial resources to support the physical activities.
- A background setting (political, legal, regulatory, social, and environmental, etc.) that is conducive to carrying out successful resource supply projects.
- Supply to a user.
- A system that brings these interdependent and continually changing factors together in a manner such that the reward of doing so is greater than the effort required and minimises the social and environmental impacts.

These establish conditions or Contingencies, all of which must be satisfied before a product can be provided.

There are often many Agents (e.g., companies) that carry out operations along the chain of physical and other activities leading to supply of a product to a user.

This focus of this report is a Final Product that is delivered to a user by an RSS, not an Intermediate Product or the output of a subsequent manufacturing process. For instance:

[1] For want of a better term this may be denoted here as the Human World Economic system (HWES) which itself is part of a wider system.

- Copper that is delivered to a user is the Final Product not the initially mined ore or copper concentrate, nor goods that may be manufactured from this copper.
- Oil that may have been pre-processed for transport and delivery to a refinery but not the refined output.
- Electricity that is generated from solar, wind, water, or bioenergy and delivered to a user, not its subsequent use.

It does not consider the uses of a Final Product in the HWES once it passes out of the RSS, such as:

- Manufacture of copper wire.
- Generation of electricity from oil or natural gas.

The elements (or components[2]) of an RSS are described and developed as a network.

2. TERMINOLOGY

The terminology used to describe the components of a resource supply system is often imprecise and may be clouded by vagueness, not only in the media but also in technical usage[3]. Terms, as used here, are described in the Glossary and, following this section, italicised at their first significant use and at other key points in the text. This usage may differ from the manner in which they are used elsewhere.

It seems unnecessary to invent new words or make tiresome explanation whenever a word such as exploration or production is used in an apparently incongruous manner, and they should be considered in the context of the activity involved.

3. WHAT IS A NATURAL RESOURCE?

3.1. INTRODUCTION

The word, *Resource*, is a general term for the *Quantity* of a useable commodity that includes both a natural source of material or energy and also a produced and processed material product or energy. This report is concerned with the production and use of naturally occurring material and energy, the *Natural resources* from which all other types of resource are created, including recycled materials that originated as natural resources.

Natural resources are of two fundamental forms[4] mass (material) and energy that require different technologies to make them useful to humans. Both may be stored for later use, mass may be physically stockpiled, batteries and dams temporarily store energy.

[2] The term Component is used to refer to all constituents of an RSS and includes the fundamental Elements.

[3] For this reason, the UNFC uses an alphanumeric classification nomenclature instead of words such as “reserve”.

[4] As described in the famous equation, $E = mc^2$, where E is energy, m is mass (material) , and c is the speed of light.

3.2. NATURAL RESOURCE: MASS (Material)

Material natural resources, in the form of mass, occur in three forms, gas, liquid, solid, each of which have their own technologies for *Production*, *Transport*, and *Processing*. They may be used as is (e.g., water, aggregates), after physical or chemical processing, or to create electrical energy. They include:

- Fuels to generate heat or energy: coal, oil, gas, uranium, thorium, etc.
- Chemical feedstock: coal, oil, gas, sulphur, evaporites, etc.
- Manufacturing (after processing, refining, etc.): a wide variety of goods.
- Aggregates: building stone, sand, gravel.
- Cement.
- Water.

3.3. NATURAL RESOURCE: ENERGY

Energy occurs in two fundamental forms[5]:

- Kinetic energy, the energy of a moving body.
- Potential energy in different forms.

The total energy of a system is the sum of its kinetic and potential energy (the Hamiltonian equation).

Kinetic energy natural resource forms include:

- Flowing water
- Tides
- Wind.
- Solar energy, the capture of photon kinetic energy that may be converted to electrical energy.

Potential energy sources include:

- Gravitational energy (e.g., energy of water stored behind a dam).
- Chemical energy bound up in chemical bonds.
- Geothermal energy, potential energy of radioactive and gravitational origin that may be used to generate electricity or for direct heating.

4. RESOURCE SUPPLY AS A SYSTEM

A *Resource Supply System (RSS)* is a set of connected activities, some of which are sequential, that must be carried out for a product to be supplied. It has a number of fundamental elements: source,

[5] Details are far beyond the scope of this this report. See [Energy - Wikipedia] for a more comprehensive account.

entitlement, physical system (Production, Transport, Processing), financial, economic, and background (legal, regulatory, etc.). All of these must fall into place before a Final Product can reach its user.

An RSS is a subsystem of a much larger *Human World Economic System (HWES).* Although not presenting the full scope of complexity, it can be instructive to consider the basic elements of a resource supply system as if it were isolated from the HWES, as in Figure 1 below:

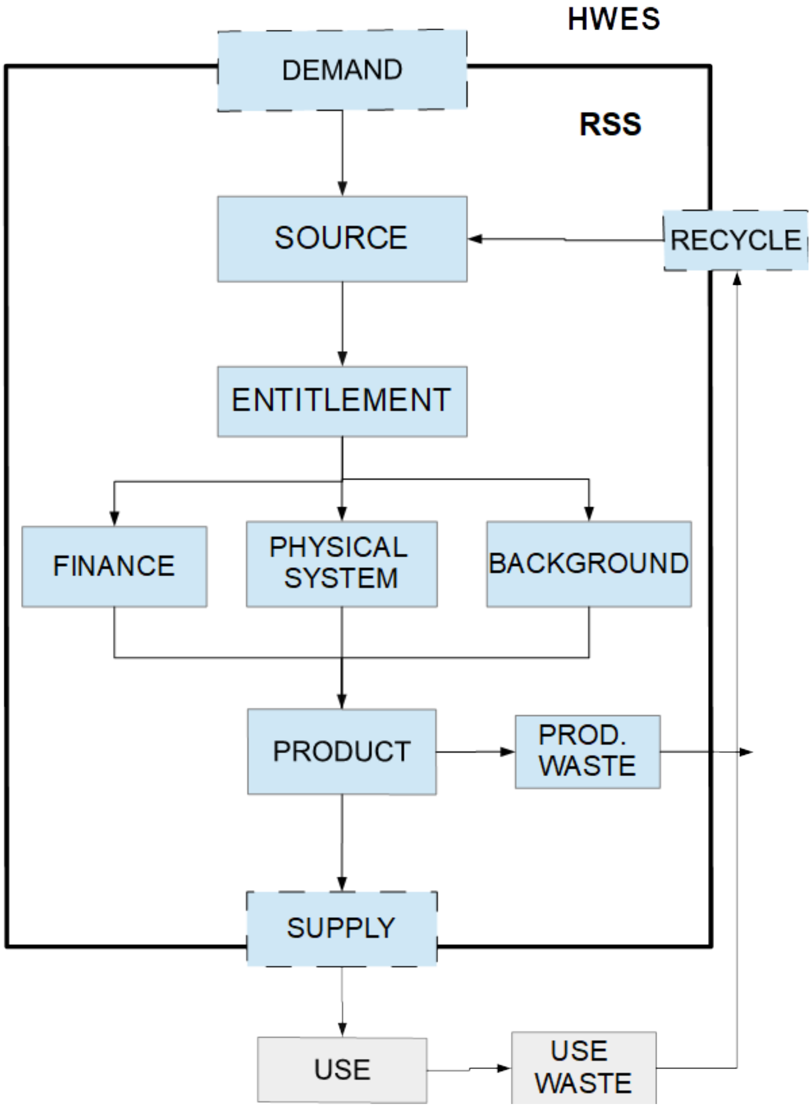

Figure 1. The basic elements of a resource supply system.

The basic structure is one of activities in the boxes that are linked as shown by arrowed lines.

- The heavy black line indicates the boundary between the RSS and the HWES.
- The boxes can represent activities of *Agents* (such as operating companies), and may contain *Decision Rules*, etc.

- Supply and Demand, with a dashed outline, are the entry and exit points between the RSS and the HWES
- Boxes with a thin outline and a light grey background lie outside, but couple with the RSS.
- The arrowed lines between boxes carry information of various types, such as quantities, monetary values, etc.

This is a simple static representation of a single *Project* and is not intended to represent a real system, which would be dynamic and complex. It can be regarded as a generic "map" of an RSS.

The entry point to an RSS is the recognition of a signal of:

- *Demand*, the interface between an RSS and the HWES. When conditions warrant, notably a considered balance between risk and reward, it may trigger action by an,
- *Agent*, an autonomous entity with defined properties that carries out prescribed activities. It is used in *Agent Based Modelling* to represent many types of entity and may be individual (e.g., a company or government) or collective (e.g., a combination of several companies or government organisations). The properties and behaviour of an agent can differ and can change over time as it reacts to information that it receives from other agents and the environment in which it operates.
- *Source***,** that, when identified and assessed to be commercially viable may be granted,
- *Entitlement* to produce and market a product by construction of a,
- *Physical system* controlled by *Operating agents* that construct and operate facilities as *Projects*:
    - *Production agents*.
    - *Transport agents* that move the resource quantities through the system and deliver it for use.
    - *Processing agents* with facilities that turn a raw resource into a desired final product.

In addition to the physical system, other conditions that must be satisfied are:

- *Financing*, the lifeblood of the system and supplied by a Financial Agent such as a bank or the securities market.
- *Background* agents set requirements that are wholly or largely beyond the control of an operating agent. They include:
    - *Legal issues* such as entitlement
    - *Regulations*
    - *Political* issues
    - *Environmental* and *Social* issues

When the above conditions are satisfied, a:

- *Final Product* is created that exits the RSS at a,
- *Supply* point, on the boundary of the RSS and the HWES, for,

- *Use*, an externality representing the manufacturing system and consumer usage of the HWES that provides the amenities on which our society relies.
- *Recycling*. At each stage of activity, processes in the RSS and also outside it in the HWES, leave a *Residue* or *Waste*. Because of changes in demand, technology, economic, and other conditions, subsequent examination of this could identify it as a potential source that may be recycled to provide a product. If this is the case, it would be added to an inventory of potential sources. In the simple model above, a *Recycle* loop may feed this back into a source inventory and could represent an element of a *Circular Economy*.

  Other factors are:

- Concepts and practices that underlie the system including:
  - *Information* and the associated representativeness and uncertainty.
  - *Contingencies*, specific criteria, or conditions that must be satisfied before a project can proceed.
  - *Decision rules* that specify conditions that must be met to satisfy contingencies to enable a project to proceed.
  - *Assessment* (including monetary *Valuation*), to provide information on resource quantities and value.
  - *Communication* to decision makers.

These elements are discussed below and are of general relevance, but every project will have its own specific conditions or contingencies that identify the actions needed by an agent. Failure to satisfy them would prevent a project from proceeding to completion. The question as to whether a contingency has been or will be satisfied depends on the establishment and satisfactory resolution of specific *Decision Rules*.

A more useful and formal presentation of an RSS is in the form of a *Network* in which the boxes of Figure 1 represent nodes that are connected by links (see Section 17.3 Networks).

5. REALM OF DISCOURSE (ROD)

Studies on resources are carried out under specific conditions, contexts, and assumptions, that can range from geological models, analytical models of various types, quantity and price forecasts, likelihood of access to market, etc. These establish a unique “*Realm of Discourse*” (ROD) for an analysis that describes the conditions, context, and the reason for examining, evaluating, or classifying, a resource or a resource supply system.

The ROD of an assessment describes what it actually includes. Put simply, “<u>exactly</u> what are you talking about?”. An example of differing RODs:

- Price conditions[6] for evaluating Proved oil and gas reserves prescribed by securities regulators:
  - The US SEC mandates a constant price that is an average of the price on the last day of the preceding twelve months at a zero percent discount.
  - The Canadian CSA mandates a forecast price at a minimum (non-zero) discount rate based on money market conditions.

- Assessments that are identical except that one includes CO_2 emission conditions and the other does not. The question of whether or not CO_2 should be included is a separate issue.

- Differing geological models, such as oil and gas reservoirs found in sediments of different depositional or diagenetic environments.

It is essential to know the Realm of Discourse of a study to understand and use its results or it can be misleading. In some cases, it is implicit, such as when an evaluation is carried out according to standards prescribed by a securities regulator but is often less obvious. Misunderstandings often occur because proponents are operating under different RODs, for instance different estimates of "reserves" between US SEC and Canadian CSA filings due (amongst other thing) to different prices as noted above.

6. RESOURCE SUPPLY MANAGEMENT

6.1. INTRODUCTION

Resource supply management involves the many components of a Resource Supply System between Demand and Supply of Figure 1. The behaviour of individual projects is usually reasonably well understood. This is not the case for a *Resource Supply System* which will often have hundreds of components with crosslinks and dependencies that form a dynamic *Complex System*, for which the response to a change is typically non-linear and unpredictable (see Section 17.4 The Resource Supply System as a Complex System). This presents significant challenges to the management of resource supply.

6.2. WHAT IS RESOURCE SUPPLY MANAGEMENT?

What it is:

- An active process with the objective of providing the timely and efficient supply of required products to world society.

How it is carried out is of critical importance and should meet the following conditions:

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[6] This illustrates a fundamental difference but details and other provisions can be found in the relevant regulatory documents.

- Resource production and use should be carried out in a manner that minimises deleterious environmental and social impacts. Changes in resource supply, especially shortfalls, and use can have a significant disruptive impact on society and should be carried out in a measured manner that limits adverse societal effects.

Balancing these potentially conflicting conditions is a major task.

6.3. MANAGING THE RESOURCE SUPPLY SYSTEM

Managing resource supply requires:

- Setting an objective for what is to be managed (quantity, financial, social, and environmental conditions, etc.).
- Developing a clear *Realm of Discourse*.
- Identifying the *Levers* that may be used to meet the objective, where "Lever" is an informal name for an action that may be taken to create a desired change in the behaviour of a resource supply system.
- Deciding how to use the Levers.
- Analysing the potential outcome of using a lever before "pulling" it, considering that it is a change to a complex system, often with a poorly understood or delayed response time.
- Assessing the results.

6.4. WHO MANAGES RESOURCE SUPPLY?

The resource management system is managed by the agents that operate the levers and make or influence the decisions on resource supply:

- The agents who operate the physical activities that provide the required products.
- Governments at various levels who grant rights to operators, establish a fiscal regime, develop policies, *legislation*, and *regulations*, etc., that govern resource recovery operations.
- Non-government, inter-government, and quasi-government agents, such as the UNECE, IASB, IEA, technical societies, and others, who can provide standards that facilitate the communication of reliable information.
- *Financial agents* that provide funding for resource projects.
- *Social agents* that apply formal and informal pressures. These have recently become prominent, inhibiting the development of resource projects, by directly or indirectly influencing government policies.

Resource supply management is a dynamic process (e.g., continuing changes in prices, transport systems, etc.) that may require revising the content or structure of an RSS and making changes as needed.

There are also factors that may be informally described as *Black swans* that arise unexpectedly and are discussed in Section 14.3. These can include civil and armed unrest, wars, and supply system disruptions, etc. It is not possible to predict the exact timing or magnitude of these, but some control may be exercised by understanding the RSS, and by contingency planning.

PART B: ELEMENTS OF THE RESOURCE SUPPLY SYSTEM

Natural resources vary in properties and use and many publications provide resource-specific guidance on their assessment[7]. Part B addresses the fundamental *Elements* of the Resource Supply System that are common to all natural resource types, as listed in Part A and shown in Figure 1. All of these are essential for the supply of a resource and failure to satisfy any one of them will result in an inability to provide a final product.

7. STARTING AND END: DEMAND AND SUPPLY

Activity in a resource supply system starts with the recognition of a Demand, the expression of a user's desire and ability to acquire a product, the basic force that drives economic activity, and typically signalled by a rise in price. A demand forecast consists of a material quantity in m^3, or electricity in Joules per year, or equivalent units. It can take many forms, but most non-renewable material resources show an initial increase often over many years, becoming asymptotic to an economically and source availability constrained supply, followed by decline. Most renewable resources generate electricity, for which the aggregate demand would be increasing, but constrained by facility capacity at the project level.

Demand forecasts are typically shown as a smooth trend, but in reality, there are often sudden significant and unpredictable increases and decreases within a time frame that may influence investment decisions.

The links between *Demand* and subsequent elements carry *Signals* that communicate *Information* to the potential resource suppliers. A signal will vary in type, quality, and level of detail, and may be the quantity or value of a product, often with an indication of potential costs, price, etc**.** It is also dynamic, changing over time, often with limited predictably. The factors that generate a demand are not discussed here.

Should an analysis of demand indicate that a supply may be developed at a *Price*[8] that would, at least, cover all the costs of production and delivery to a user, it can generate a requirement for financing, commencement, continuation, or cessation, of physical activities.

[7] There are many resource specific publications such as those of the UNECE EGRM, COGEH, PRMS, CRIRSCO.
[8] The word “price” is used here in a general sense that may include the exchange of money, barter, or services.

A *Market*[9] is a venue for the sale and purchase of products and determines a price in or, for the final product, at the *Supply* point, the exit point of the resource supply system and varies in scope from local to international. It allows the monetisation of a product and the payment of debts that have been incurred during the recovery process. Most resource transactions are governed by contracts that specify factors such as quantity and quality, price, ownership transfer point, product delivery schedule, etc., and are usually the subject of considerable negotiation.

8. FINANCING

8.1. INTRODUCTION

Financing, the provision of capital, is the lifeblood of resource recovery and differs from the physical and general background contingencies because capital can be readily and rapidly deployed elsewhere. The greatest need for financing is during construction of the physical facilities. All projects require that:

- The available financing is adequate to fund current and ongoing activities.
- The ultimate financial reward is anticipated to be greater than the cost of carrying out a project.

This does not imply that this certain to be met by every project – many projects fail – but that the aggregate of projects should do so, at a level of aggregation that increases from the project to a country or government, to its highest level of society in general.

8.2. SOURCES OF FINANCING

Sources include:

- Self financing.
- Securities (stocks, bonds, etc.) issued to private and public[10] investors. An investor in securities anticipates a return in the form of an increase in its value or from dividends. Securities sold to the public are governed by national securities laws and monitored by securities regulators for adherence to reporting standards and by outside agencies such as brokerages. Securities sold to private investors will usually be governed by general legislation and contracts. They are also monitored but the results are reported only to the investors.
- Debt, typically from banks and private investors. A debt loan is governed by general legislation and contracts, usually has a term at the end of which it must be repaid and may require periodic interest payments. A debt lender will carry out periodic reviews to ensure that the borrower is

[9] See https://en.wikipedia.org/wiki/Market_(economics) for a more thorough discussion of markets.

[10] Companies that issue securities sold to the public may be referred to as "Reporting Issuers" because securities law requires them to make regular reports.

able to make the interest payments or to repay the loan. If a review indicates a risk of failure to do so, it may result in the loan being recalled and bankruptcy of the borrower.
- Financing by governments including direct investment, subsidies, and policies such as tax and royalty relief.

9. SOURCE

9.1. INTRODUCTION

A *Source* is the starting place or origin of a product. It may be:

- Natural
  - Subsurface, such as a metallic ore body.
  - Surface such as water, sunlight, wind, etc.
- Anthropogenic, the residue of human use of natural resources, such as biowaste or mine tailings.
- Technical and scientific activity that identifies new types of uses and sources.

To be commercially accessed, a source must be concentrated naturally (e.g., oil, gas, solid minerals) or artificially by transport (e.g., biowaste), in sufficient quantity and quality, such that a viable project can be considered. The same product may be generated from sources in separate locations and of distinct types (e.g., iron from hematite, Fe_2O_3, or magnetite, Fe_3O_4), with different transport and processing requirements.

Just because a source exists, even if there is the technology to exploit it, it may not be commercially viable, for economic, political, or other reasons. It could become viable due to changing conditions, such as an increase in price, or become a target for technology development. An example of the latter is the US Colorado and Utah Eocene Green River Formation, the largest oil shale deposit in the world, with an estimated three trillion barrels of oil resources. Although experimental projects have recovered some oil it is not commercially viable at the present time.

A source is a quantity that may be[11]:

- *Known (Identified* or *Discovered)*[12]*.* A source that has been identified and is either:
  - *Contingent*, identified but not viable because of unsatisfied technical, economic, social, environmental, or other contingencies, or,
  - *Reserve* that is viable to produce with no remaining contingencies.

[11] Resource classification systems such as those of the PRMS, CRIRSCO, the UNFC, and others, provide an estimated resource quantity and its associated uncertainty.

[12] Methods of assessing sources at a project level are well developed and described in the technical literature.

- *Unknown (Unidentified* or *Undiscovered)*[13]. Although this may seem a contradiction, methods of estimating them are well developed for many resource types, the potentially recoverable portion of which may be classified as a *Prospective resource*.

Designation as a *Known source* requires more than a simple assertion and it must satisfy:

- Demonstrated production, or
- A potential for production based on tests, analyses, or other evidence that is relevant for a particular resource type. Evidence of presence (e.g., trace amounts) alone would not be adequate.
- Evidence that there is a quantity with the potential to support development. While this is a matter of judgement, especially at early stages, it is sometimes described as a "significant" quantity with the comment that this implies that it is sufficient to warrant a study[14].

A source always has a remaining *Unrecoverable*[15] proportion because of a less than one hundred percent *Recovery factor*.

A distinction may be made between estimates of an:

- *Endowment source*, an aggregate of known and unknown sources in a region and not necessarily attributed to a defined project (e.g., world or national supply of iron ore). It is typically used for large scale planning or exploration studies and usually carries a significant degree of uncertainty.
- *Project source,* the portion of an Endowment source that is associated with a specific project.

Considerable effort is devoted to finding new sources with an *Exploration*[16] project. There is no universally recognised terminology for the stages of exploration, but a modification of terminology that is commonly used for oil and gas exploration[17] may be applicable:

- *Play*: A bounded geographical area or geological volume that may contain unidentified resources.
- *Lead:* A potential resource within a play that requires more data acquisition and/or evaluation to be classified as a prospect.
- *Prospect:* A potential resource within a play that is sufficiently well defined to be a viable target for a project.

Sources may be assessed under different conditions (see Section 5 *Realm of Discourse*) that should be clearly described in reports.

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[13] For example, see: Chapter 22.6, Evaluation of Undeveloped Lands, in Determination of Oil and Gas Reserves, Petroleum Society Monograph 1 (2nd edition), Canadian Institute of Mining, Metallurgy, and Petroleum, 2004, for a short account of methods for oil and gas. Drew, L., 1997. Undiscovered Petroleum and Mineral Resources, Plenum Press

[14] See PRMS 2.1.1 Determination of Discovery Status.

[15] That is, unrecoverable under current conditions which may change.

[16] The term "exploration" is typically applied to subsurface resources, but it is here also applied to other resources.

[17] From COGEH, adapted from Rose, 2001 (citing McCrossan, 1973; Roy, 1975; Baker et al., 1986; Miller, 1986 and White, 1992) and PRMS.

9.2. SOURCES

9.3.1. Introduction

Decisions on source development depend on an adequate *Characterisation*, the level of detail and content of which will vary. Additional information may be required for assessment of viability but the minimal characterisation would include estimates of potential:

- *Quantity*, e.g., m^3 oil, tonnes of copper, solar power in joules m^{-2}, etc.
- *Quality*, e.g., API of oil, m^3 copper/m^3 ore (percentage or ppm), hours of sunlight per day for solar energy, etc.

Production forecast and valuation methods are well developed for all resource types. Their description is beyond the scope of this paper.

9.3.2. Source Types

9.3.2.1. Non-Renewable Sources

A non-renewable Source (e.g., oil and gas pools, ore bodies) is typically described by a probability density distribution of quantity, with a large number of small and a smaller number of larger estimates, The distribution would be trimmed to exclude the smaller sources that fall below a minimally acceptable *Cut-off* quantity or quality, based on technical, economic, and other criteria. often with a *Pareto Distribution*[18] or a left truncated lognormal distribution. The Cut-off for an identified source would be lower in quantity and/or quality than for an unidentified source since the cost of identification is a sunk cost that has yet to be incurred for the latter.

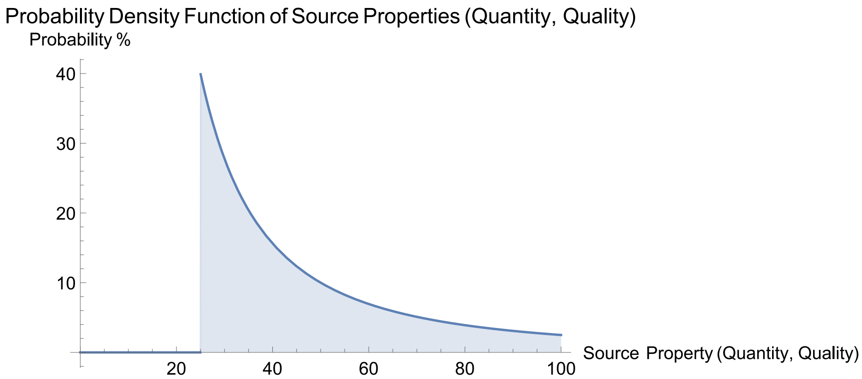

Figure 2. Example of Pareto Type I Probability Density Function showing the probability that source properties, quantity, or quality, will exceed a minimum size cut-off of 25 and be less than 100.

[18] A Pareto Type I Function has a minimum value. A lognormal distribution with a truncated left tail can approximate a Pareto distribution.

Figure 2 illustrates the probability of a finding a source, with a horizontal axis that represents quality or quantity with a minimum size or quality cut off greater than 25 and less than 100. The cut-offs will depend on the nature of the source and on economic considerations.

Idealised distributions may be used for examining the behaviour of a resource supply system but should be replaced by distributions for specific resource types or analogues if they are available.

9.3.2.2. Renewable Sources

The ideal renewable source may be considered more or less constant over a lengthy period, but supply can have seasonal, diurnal, or weather related variations and be curtailed by facility degradation:

- *Solar energy* will vary seasonally, is not available at night or during unfavorable weather and, although solar panels can have a life expectancy of up to 30 years, performance typically degrades by about 1% a year[19].
- *Wind energy* is inconstant and wind turbines have a lifespan of 20 -25 years[20].
- *Geothermal energy* plants typically have a lifetime of 30 years[21]. In some cases, there is a drawdown of the reservoir energy that may result in a reduction, interruption, or cessation of energy offtake rate for a time, but may eventually be replenished by heat migration from the surrounding reservoir.

9.3.2.3. Anthropogenic Sources: Recycling

Anthropogenic resources owe their origin to the production and use of natural resources, as an unusable and discarded anthropogenic *Residue*, usually described as *Waste*. Developments such as changes in price or technology may lead to the recognition of what was previously regarded as waste to be a potential source. It may not be immediately commercial, but should be recognised in an inventory, potentially leading to a process to recycle it as a viable source. For instance:

- Coal and mineral mines typically leave large amounts of waste, the residue from which the material originally of interest had been separated.
- Tailing pond sediments from oilsands production that may contain titanium.
- Slag from mineral smelting.
- Residue from many chemical processes.
- Radioactive waste.
- Organic waste, such as food processing residue.
- Etc.

[19] How Long do Solar Panels Actually Last? (solarreviews.com)
[20] How Long Does a Wind Turbine Last? | Kurz Industrial Solutions
[21] Life-Cycle Analysis Results of Geothermal Systems in Comparison to Other Power Systems (energy.gov)

The goods created from resource products often have a limited life and may also generate large amounts of waste. For example:

- Plastic packaging, bags, etc.
- Cardboard packaging
- Aluminium foil, tin (iron) cans.
- Electronic devices containing rare earth elements.
- Etc.

Figure 1 shows the recycling of waste from both the RSS and subsequent usage that may contain a desired Final product.

At the present time, although there is significant recycling of elements, such as iron and gold, recycling of most of them, including the rare earths, is limited[22].

9.3.2.4. Technical and Scientific Developments

Technical, and scientific developments continue to identify new sources, product types, uses, and improvements in the use of existing resources. They may also lead to partial substitution of one resource by another, for instance, a resource supply system for iron may be studied as if it were a closed system that only considers iron, but would be affected by a growth in replacements such as plastic, aluminium, engineered wood, etc.

Steam technology was fundamental to the industrial revolution. More recently, improved techniques in drilling and fracturing created a new commercially viable source, oil, and gas from low permeability reservoirs, with significant changes in the structure of the petroleum market. Success in the current research into energy from fusion, could have a profound effect on energy supply that would ripple through an energy RSS. There is also a great amount of research into fields such as material science, that could have an impact on resource supply.

9.3. SOURCE INVENTORY

A source inventory[23] is a data depository of information on Known (Identified) and Unknown (Unidentified**)** sources of any sort. It is an important feature of a resource supply system that enables agents of all sizes and types to plan for future supplies. The information that it contains will differ in Realm of Discourse*,* detail, and maturity, ranging from the early stage of a Play to fully developed Projects. Changing conditions, such as a forecast price increase or political contingencies, can result in action that results in a potentially viable supply.

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[22] Metal-lifespan analysis shows scale of waste (nature.com)
[23] An example of a minerals inventory is the USGS National Minerals Information Center (usgs.gov)

10. ENTITLEMENT

Entitlement is the set of rights, granted by a resource owner to an operating agent to search for, develop, produce, and sell, a resource. A search for a source at the stage of a Play may proceed without entitlement but it is invariably a prerequisite for an operating agent before incurring the major cost of constructing a physical system. An entitlement is typically embodied in detailed legal contracts[24].

The interests of the grantors and the grantees are not identical, but complementary. The incentive for a sovereign jurisdiction to grant entitlement is the potential for a supply of a resource, jobs, and revenue from royalties and taxes. For a company, it is the potential for a positive cashflow from a resource project; an example of different Realms of Discourse for the same resource (see also Section 5 Realm of Discourse).

11. THE PHYSICAL SYSTEM

11.1. INTRODUCTION

The physical processes that follow the recognition of a demand, identification of a source, confirmation of economic viability, and entitlement are carried out as *Projects*, constructed, and operated by agents:

- Production[25]
- Transport
- Processing
- Possibly Storage

Each of these contain many details, including production forecasts, transport capacity, timing of activities, etc. There may be *Intermediate Products*, *By-products*, and *Storage* that introduce a time delay, custody transfers, etc., with an effect on the supply of a *Final Product* and on its discounted value.

Manpower and material resources (steel, cement, etc.) are required throughout the resource supply system, especially during construction, and are a significant element of capital costs that is not recovered until a product starts to be delivered to a user. Lack of skilled manpower, material, and infrastructure can lead to increased costs and project delays.

11.2. PRODUCTION

[24] An exception may be artisanal mining.

[25] The term “Recovery” is typically used for non-renewable resources, to describe the physical production of a resource (even though it implies getting something back that had previously been owned!). Although not usually used for renewable resources, it is an equivalent activity. The more general term “Production” is used here for both renewable and non-renewable resources.

Once a source has been identified, its value can only be realised if there is a technically and economically viable production process. Even for one resource type (e.g., light oil) these are varied in design and construction.

11.3. TRANSPORT

A source is rarely found close to where it is needed, and the construction of a transport system is often a major endeavour, the nature of which depends on the properties of the source. It may involve trucks, conveyor belts, pipelines, electric transmission lines, rail cars, oil and gas tankers, cargo ships, etc., and a supporting infrastructure of roads, gas compressor stations, ports, etc. A transport system may be fixed (e.g., pipelines, electrical grids) or flexible with alternative routes (e.g., shipping). It is often carried out by different agents than for production and is typically governed by contracts that specify quantities, standards, etc.

Limitations or disruption of transport facilities such as a failure to build pipelines or winterize energy systems can cause considerable disruption or even render the supply projects non-commercial.

11.4. PROCESSING

A few resources may be recovered in a directly usable form, but most require processing before supply to a user, often under contract provisions on quality. Processing may be physical or chemical, take place on site, at several points along a transport system, and immediately before delivery to a user.

11.5. STORAGE

All elements of the physical system of the RSS employ some limited storage as a temporary part of the larger system, for example:

- Temporary stockpiles of raw mined, partly processed intermediate, and final products.
- Oil in a tank farm awaiting shipment or delivery to a user.

In such cases, storage probably would not be considered as a separate project. However, for some types of resource, storage is a core element of the physical system, often with major capital costs, for example:

- A Strategic Petroleum Reserve
- Water behind a dam for hydroelectric generation.

The generation of electricity by projects that are weather or diurnal dependent is intermittent and although some of these are commercially viable under prevailing conditions without storage, others would require large scale storage to be viable. Electricity can be stored in batteries, but commercially viable technology for large scale storage is at an early stage of development. Construction of a Network or Agent Based Model for such projects may need to incorporate this type of storage.

11.6. SUPPLY

Supply and delivery to a user is usually governed by a contract that sets out terms for the transfer of ownership of a Final Product to a user at a *Sales Point*, such as quantity, quality, contract life, etc. Periodic audits are often required to ensure that the contract terms can be honoured over the lifetime of the contract.

12. THE BACKGROUND

12.1. INTRODUCTION

The physical activities of resource supply are carried out against a *Background*[26] of contingencies, that are extrinsic to, and largely beyond, the control of a physical project operator. Unlike the elements of the physical activities, they are not necessarily sequential. They are often well established but changes[27] in them may have a significant impact on the ability to supply a Final Product.

Economic viability underlies all parts of the resource supply system and is discussed separately, rather than as a component of the background (Section 15.4 Project and System Viability). Financing is also discussed elsewhere (Section 8 Financing)

Additional background contingencies are discussed below, and all have significant complexities that are not addressed.

12.2. LEGAL AND REGULATORY CONTINGENCIES

A sovereign jurisdiction[28] will establish *Legislation* governing resource activities that is generally supplemented by *Regulation*, the rules, and directives for carrying out the intent of legislation. These are often detailed and may recognise standards developed by specialised professional technical organisations. The quality of the legal system under which resource projects are carried out is an important consideration for an operator.

In addition to specific legislation and regulation, resource supply projects may be subject to other types of legal procedures (e.g., ownership disputes, contracts, securities, etc.) that are not addressed here.

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[26] Sometimes called Framework or Milieu.

[27] Some of these changes may be unanticipated, such as the proverbial "Black Swans".

[28] Resource production may also take place under informal or unsettled conditions such as regions of civil unrest, but similar considerations apply.

12.3. POLITICAL CONTINGENCIES

A *Political Contingency* is action by a controlling agency that can influence, impede, prevent, or facilitate, the ability to proceed with a project. Its scope may be international, national, or local, and could include political or social unrest, armed unrest, war, government, or non-government action that affects a project. *T*he magnitude of the impact can range from minor, with limited and short impact on a single resource, to major long term with widespread consequences.

A significant issue for an operating agent is the risk of adverse changes to the conditions under which resource recovery activities are being carried out, due to political actions (e.g., nationalisation, increase of taxes, royalties, civil unrest, war, etc.). It is not unknown for a jurisdiction to change the terms of a lease when an operator has borne the risks of exploration and identified a viable source.

12.4. ENVIRONMENTAL AND SOCIAL CONTINGENCIES

When we talk about the viability of resource recovery, we typically think about fiat money, usually for individual recovery projects, but there are other factors that cannot readily be measured in this manner. These may include concerns about the social and environmental effects of resource projects, strategic concerns about resource supply, etc., that could be accommodated by defining an appropriate ROD. All resource projects have an environmental impact that may trigger social issues. The consequences of these can have a major effect on the timing or validity of a Resource supply project.

Environmental contingency. The physical, chemical, and biological impact on or changes to, the surrounding pre-existing environment, due to a project (e.g., heavy metal contamination in soils or water, disruption of wildlife habits and migration characters, etc.).

Social contingency. The impact on humans and society, of environmental changes, such as:

- Effects stemming from environmental changes (e.g., health issues due to heavy metal contamination).
- Changes in social systems and structures, (e.g., ownership claims, traditional land usage, land and other value changes, changes in local population community structures, the creation of jobs and economic activity, etc.).

The term *Social licence* is an often used portmanteau phrase to describe the collection of social and environmental issues related to a project. It is colloquially useful for this purpose, but the specific issues are likely to be different for every project and there may not be agreement on what they are (i.e., different RODs). For this reason, it is not recommended as a classification or decision criterion and the contingencies that constitute the social licence should be addressed individually.

Resource supply operations may be subject to legal and regulatory requirements related to social and environmental issues, notably for the many countries that have committed to the UN Sustainable Development Goals (SDG) and the Paris Climate Agreement. Receipt of the relevant regulatory approvals is essential to the initiation of a resource project and refusal or undue delay may result in its abandonment.

12.5. NATURAL EVENTS

All natural resource projects are subject to weather and other natural events that may inhibit resource supply, including the destruction or damage of physical plant.

PART C: CONCEPTS

The objective of resource management is the supply of mass and energy and is underlain by key *Concepts*. Some of these have been noted in previous sections and this section summarizes them and provides more detail.

13. INFORMATION

13.1. INTRODUCTION

Each stage of the management of a resource supply system is mediated and assessed by analysing *Information*[29] that is passed along *Links* between *Agents*. On receipt, an agent will typically carry out an analysis and submit the result to a *Decision rule* that determines subsequent action as illustrated in the simple example of Figure 3 below.

The *Links* in an RSS carry information in the form of a *Signal* that may be digital or analog, electronic, physical (e.g., a postal system), verbal communication by phone or in meetings, etc. Types of information include:

- Quantity and quality of a resource.
- Financial.
  - Current status of financing (loans, securities, etc.)
  - Current evaluation of resource assets
- Other information required for a decision (e.g., status of regulatory approval) or results of an analytic procedure.

Contingencies and Decision Rules are discussed in more detail in Section 13.3.

[29] Information - Wikipedia contains many references to in depth material on the concept of information. Further discussion of information relevant to resources can be found in the report, Principles of Resource Classification, ECE/ENERGY/GE.3/2020/3.

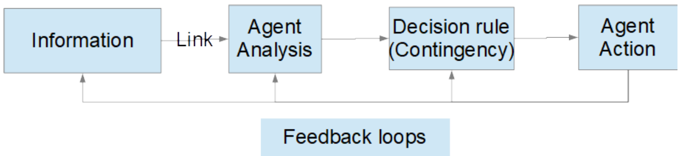

Figure 3. Simple example of the transmission of information

13.2. UNCERTAINTY, CUT-OFFS, AND RISK

The information that is available for decisions on resource supply projects is invariably *Uncertain.* and may be *Biased*[30]*.* It is often treated as if different elements of information were independent but there may be considerable dependence, the degree of which is hard to assess, that can introduce further uncertainty.

Any project has a range of outcomes with the uncertainty represented by a confidence interval, a range of values and the probability of occurrence within that interval and may be continuous or discontinuous. It is often expressed graphically by different types of distribution.

Some of the possible outcomes will fall below a *Cut-off* value (see Figure 2 Example of Pareto Type I Probability Density) that is based on specified criteria that separate non-viable from viable ventures. They are often used in *Decision rules* to separate the result of analyses into different sets, such as:

- A value of greater than 5% porosity for pay in a gas reservoir, where rock of less than 5% porosity is not expected to contribute to flow into a borehole.
- An anticipated minimum probability of 80% of receiving regulatory approval.
- Project outcomes from those that are viable, with a discounted positive NPV rate of return, from non-viable with an NPV of less than zero.
- Project *Economic Limit* below which production is no longer viable.

Risk is the probability of failing to meet a desired outcome (e.g., 10% NPV greater than zero).

Quantitative information can be assessed by the well developed methods of statistics, including the estimation of *Subjective probabilities* (e.g., by Delphi methods[31]), and there are methods of quantifying qualitative estimates[32].

13.3. CONTINGENCIES AND DECISION RULES

A Contingency is a criterion or condition, all of which must be satisfied before a project can proceed to completion and supply [33]. They are many and varied, for example:

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[30] There are several types of bias and it is not always intentional.
[31] [Delphi method - Wikipedia]
[32] The quantitative expression of qualitative information is discussed in more detail in "Principles" (op cit.).
[33] Exceptions occur such as the continuation of production on social or other grounds when it is no longer economically viable, but this is not sustainable on a large scale.

- Availability of adequate financing.
- Probability of success of an exploration well.
- Receipt of regulatory approval.
- Etc.

Whether or not a contingency is satisfied may be determined by a *Decision rule*[34], a statement of a condition that determines if a contingency has been satisfied, that assists an agent in deciding on an action (which may be to do nothing). It is sometimes described as being inside a *Decision Gate*.

In an abstract sense, a Decision rule is a function that, when fed relevant information, maps an observation (embodied in the information) to an action with a specific objective.

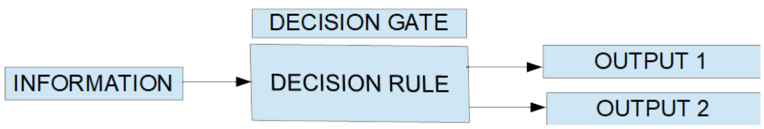

Figure 4. A Decision Rule with input and output.

The general structure is:

If {Statement}
    Then {Do This}
    Else {Do That}

The content of a decision rule will depend on the decision to be made and can take many forms. It may be:

- *Deterministic*, such as, "Has regulatory environmental approval been received?", with a Yes or No answer.
- *Probabilistic* such as, "Is the probability of receiving regulatory environmental approval ≥ 80%?".

Decisions are typically made under conditions of uncertainty, in which case, the decision criterion will be probabilistic, often subjective, and depend on a level of acceptable risk. For example, a decision to fund and commence project construction could be acceptable in some cases if the probability of receiving regulatory approval was moderate (e.g., 70%), in other cases certainty (i.e., 100%) might be needed.

[34] There is a considerable literature on Decision theory and Decision making, the details of which are not fully addressed here.

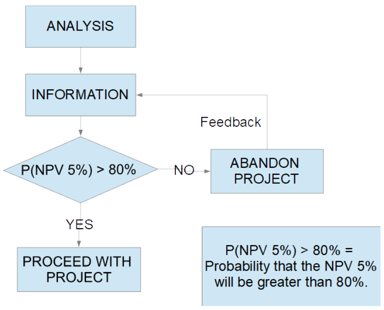

Figure 5. Example of a Decision Rule, "Is the probability that the NPV discounted at 5% will be greater than 80%?"; if "Yes" proceed with project, if "No", abandon project".

13.4. METRICS

In addition to formalised resource classification, measurements made and analysed at all points along a resource supply chain yield a wide variety of metrics on quantity and quality, financial reporting, project evaluation and status, etc. Many of them use established standards either local (e.g., standard temperature and pressure criteria for natural gas, although this may differ between jurisdictions or contracts) or international (e.g., the SI system). There are also non-standard metrics that may be informative, such as the widely used petroleum industry metric of "finding and development costs," for which there is no formally established technical standard and should be used with care.

There may be mandatory standards for local jurisdictions or contracts, and resource report metrics should describe the standards that have been used and users of the information should ensure that they understand them.

14. TIME AND CHANGE

14.1. TIME

Resource supply systems are dynamic and almost all components change, but not at the same rate or time. Some, such as Product prices and solar energy generation, change almost every day with some limited predictability. Others, such as regulatory requirements may remain constant for long periods but can change abruptly. Project development assessment and planning should take this into account. The time value of money affects all aspects of resource projects and is discussed in the following section.

14.2. CHANGE

The changing parameters of an RSS element form a time series that may be predictable to some extent and can be characterised informally by the:

- Type of change:

- Trend, steady change (including zero) that is reasonably predictable, such as the production decline of many gas wells.
- Random "noise" up or down. Most data exhibit this.
- Cyclic/seasonal variation (e.g., the annual seasonal changes in the demand for gas supply for heating).
- Change with limited predictability that is due to extrinsic factors, such as a change in price, taxation by a government, etc., also *Black Swans*[35].

- Magnitude and direction of change and its impact on resource supply:
  - Positive, such as a major increase in demand or price for product, is usually welcomed but may bring its own problems if there is an inability to respond in a reasonable time.
  - Negative, if large and continued can have adverse effects.

- Rate of change, which affects the ability of a resource supply system to respond effectively. A change that occurs in a short time may have a catastrophic effect whilst the same change over a longer period may be manageable.

14.3. EXTREME EVENTS (BLACK SWANS)

An extreme event is a very low probability event and could have a significant impact on the supply of a quantity of resource. The term "Black swan" is a colloquial term for such an event, usually recognised a posteriori.

Although considered to be unpredictable in magnitude and timing, a very low probability event typically has a probability of occurring within a specified time interval (the proverbial "hundred year flood"). This can be modeled by a Poisson[36] process that defines:

- An event, e.g., a > 50% decrease in transport capacity for > 3 months.
- A probability that the defined event will occur, e.g., 0.5%
- During a time interval of interest, e.g., 5 years.

Extreme events are varied in direction (positive and negative) type, magnitude, and duration, can affect any of the components of a RSS, and could also trigger other changes throughout the system.

The impact of the event should be considered separately from the event. What constitutes a significant impact depends on the situation and the same event may have different impacts on different agents in an RSS, organisations, and users. The ability of an organisation to accommodate it depends on its resources and capability, and it would be prudent to identify and make contingency plans for a disruptive event. A diversified system with several sources, transport, and processing options, is likely to be most resilient.

[35] Black swan theory - Wikipedia
[36] Poisson distribution - Wikipedia

Extreme events will have varied origins but may have their origin in the properties of an RSS as a complex system (see Section 17.4. The Resource Supply System as a Complex System).

Recent examples of "Black swan" extreme events with significant impacts on an RSS are:

- The 1996 short out of a power line in western Oregon that triggered a catastrophic cascade of power outages across the western US. A similar event occurred in the northeast in 2003.
- The 2008 financial collapse, with worldwide effects.
- The stranding of the Evergreen container ship in the Suez Canal in 2020 that had a widespread impact on the global supply chain.
- The invasion of Ukraine by Russia, with a major, ongoing, impact on energy and food supplies.

Further details are beyond the scope of this paper, and a more sophisticated view is provided by McPhillips et al[37], who discuss the definition of extreme events, and by statistical *Extreme Value theory*[38].

15. RESOURCE SUPPLY SYSTEM ASSESSMENT

15.1. INTRODUCTION

A resource is *Characterised* by a combination of the geography, geology, engineering, analogy, statistics, economics, and the background factors. This can range greatly in content and quality and may include estimates of quantity, quality, values, the associated risk, and the probability of success or failure and uncertainty in the quantity, and other factors. Should it indicate a potential for the supply of a resource, further analysis may be carried out for an economic *Assessment* or valuation to assess its economic *Viability*, usually presented in the form of an *Evaluation Report*.

Assessments may be carried out for:

- *Projects* that are geographically limited in scope and directed to assessing the:
    - Financing of resource recovery projects (e.g., by banks, securities market, etc.).
    - The viability of operational investment decisions (e.g., to mine or drill).
- *Endowment* resources (e.g., by governments, NGOs etc.) to answer questions such as "will the supply of resource X meet the anticipated demand for the next Y years?". It may have limited geographic scope and could also address issues such as environmental, social, or political constraints.
- Studies to develop fiscal policies (e.g., taxes, royalties, etc.).

Every resource type has its specific factors, but the major ones are:

[37] McPhillips et al 2018, Defining Extreme Events: A Cross-Disciplinary Review.

[38] Extreme value theory - Wikipedia

- Entitlement terms.
- Technical capability. The assessment of a physical process to supply a resource and to estimate the quantity and quality, manpower, material, and a timetable of their supply and use.
- Financial resources necessary to carry out a project.
- Economic viability.
- The background against which a resource recovery project is carried out (regulatory, social, environmental, political viability, etc.).
- A timetable of activity for the above.

Although an RSS may be modelled as a closed system, in reality it is part of a larger system that interacts with its surroundings to a greater or lesser extent. The factors that may affect an assessment can be divided into:

- *Internality,* a cost, or benefit that affects a participating entity in a project, such as project Capex and Opex.
- *Externality*[39,40] A cost or benefit that affects an entity who did not choose to incur that cost or benefit and over which it often has little or no control.

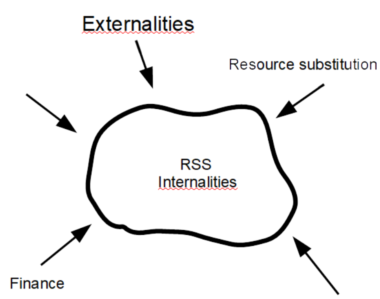

Figure 6. A resource supply system with a boundary between the Internalities for an RSS Closed system and the Externalities of the surrounding Open system.

An assessment should consider the factors that are significant and provide the information that is relevant to the objective as described by the Realm of Discourse that is, to be, "be fit for purpose".

15.2. OBJECTIVES, PROJECTS, AND SCENARIOS

All resource assessments have an *Objective*, a *Project*, and *Scenarios*:

[39] But see the comment by K. Collins, "No such thing as an externality," in Arthur, 2020. Complexity Economics, p. 315.
[40] These could include the UN Sustainable Development Goals.

- Objective. Every project is carried out with the intent of achieving an objective that should be brief, clear, and measurable. It may be implicit for routine projects, but a clear objective is particularly important for larger and less routine projects.

  Examples

  - Drill additional wells in the XYZ discovery to decide whether it contains a resource quantity that warrants further investigation.
  - Carry out a geophysical survey to assess the petroleum potential of the ABC region as the basis for exploration drilling.
  - Review the ABC region to determine the optimum site for a solar energy project.
  - To assess policy alternatives for resource taxation.

- Project[41]. A definition that can apply to any type of resource is:

  "A defined activity, or set of activities, that is directed towards the supply of a final product."

  For example:

  - A geophysical survey to identify potential oil, gas, or mineral deposits.
  - Construct a wind energy facility with the potential to generate XXXX of electricity pa.
  - Forecast of a potential supply of a resource from a project.
  - Forecast of the potential revenue to a government from resource activity in parts, or all, of its jurisdiction.
  - Develop a mining property.
  - Power line construction.
  - Assess the impact of tax or royalty changes.

- Scenario. A scenario describes the specific details, activities, and conditions under which a project is assessed, such as timing of activities, forecast production rates, and costs and provides the basis for making decisions. The same project may be assessed under several scenarios (i.e., RODs), for example, for the same project:

  - The timing to drill five wells:
Scenario 1: 5 wells in year 1, or,
Scenario 2: 3 wells in year 1 and 2 wells in year 2.
  - Regulatory reporting in Canada and the US:
Scenario 1: Constant prices for the US SEC.
Scenario 2: Forecast prices for the Canadian CSA.

[41] Other definitions of a Project are given in the UNFC 2019, COGEH RESOURCES OTHER THAN RESERVES (ROTR) 2016, and PRMS 2018 and although CRIRSCO uses the term "project", it is not defined.

15.3. TIME VALUE OF MONEY

Financial resources are essential to the development of resources. The time value of money is an important factor, and costs, revenue, loan payments, etc., are incurred at a point in time, and are usually discounted. A significant aspect is the time from the inception of a resource recovery project to first date of payment on delivery to a user. Although this may be limited for minor projects, it can be many years for a major project and, if extended, can make a project economically unviable.

15.4. PROJECT AND SYSTEM VIABILITY

15.4.1. Project Viability

A resource supply project will be viable only if all the requirements described in the previous sections are satisfied. The Physical System of production, transport, and processing is carried out with an expectation that the reward of supplying a resource is greater than the effort of acquiring it. It involves forecasts of production and estimates of Capital (CAPEX) and Operating (OPEX) expenditure, fiscal terms, measures of Uncertainty and Risk, and is typically measured by estimating a *Risked discounted net present value* (RDNPV), supplemented by accounting measures and additional information. The economic viability of a project is also greatly subject to the fiscal or regulatory regime under which it is carried out, changes in which can improve, impair, or destroy, economic viability.

The agents of the Physical System are subject to the exigencies of the financial markets for a positive return on investment for a project. Details of methods of assessing project economic viability are beyond the scope of this paper but can be found in the technical literature.

A project will have an expectation that its RDNPV will be greater than zero, but not all projects will attain this.

15.4.2. System (Aggregate) Viability

A Resource Supply System is an aggregate of many projects that will tend to diversify risk and is typical for governments, and larger operating companies. Although they are interested in timely returns, they are often able to take a longer time view and to consider more than purely monetary issues.

The financial and other resources of a society are finite and, however it is measured, over time, the rewards for supplying a resource must be no less, preferably greater, than the effort and costs required to carry it out. Depletion of the assets of an organisation or the accumulated wealth of a country in this manner will ultimately destroy its economy.

PART D: COMMUNICATION

An essential part of an RSS is the communication of reliable[42] information to decision makers of many types: operating and financial agents, governments, NGO's, technical bodies, purchasers, users, etc.

16. REPORTING

16.1. INTRODUCTION

A resource assessment usually provides a large amount of detail that demands specialised knowledge to understand and the information needed by a decision maker is usually summarised in a report at a level of detail and content that meets the objective of its user, that is, to be "fit for purpose".

16.2. RESOURCE CLASSIFICATION

Resource Classification simplifies the status of resource projects by classifying an estimate of a recoverable or potentially recoverable resource quantity according to a prescribed standard. The basic information is estimates of Low, Medium, and High estimates of Quantity for:

Unidentified, potentially available

Prospective resource, quantity potentially available if identified and developed.

Identified:

Contingent resource, available subject to satisfaction of outstanding contingences

Reserve, currently producing or available with no contingencies.

There are several resource classification systems, including:

- For financial reporting (e.g., USA SEC, Canada CSA, etc.)
- Resource specific (e.g., petroleum PRMS, minerals CRIRSCO, solar, geothermal energy, etc.)
- National (e.g., Russia, China, etc.).
- International (the UNFC), the only one that covers all resource types but, despite its merits, it is more complex than is needed for many purposes and not currently recognised by financial bodies.

Although there is an underlying commonality, each of these has its own guidelines that may result in differences.

[42] Reliability may be established by ensuring the information provided is auditable, QA/QC etc.

16.3. CONTENT OF A REPORT

A report should include, but not be limited to:

- A statement of the Realm of discourse.
- Location, ranging from limited to country wide or more.
- A description of the resource.
    - An estimate of its quantity and quality and the associated uncertainty.
    - An assessment of its economic and general commercial viability.
    - Technical information, such as maps, well data, tests, etc.
- Description of the recovery technology including whether it is:
    - Developed
    - Under development
    - Undeveloped
- Market access.
- Economic analysis.
- Relevant contingencies to be resolved, including non-technical issues.

The information in a prescribed or full technical report may be appropriate for an audience that typically has, or has access to, expert knowledge. However, communication of resource activity may also be to a less expert audience that lack this expertise, such as the public, and in other forms (e.g., news releases, corporate presentations), in which case, additional explanation may be needed.

16.4. PRESCRIBED REPORTS

The content of a report may be prescribed in detail:

- By regulatory bodies such as the Canadian CSA for oil and gas (NI 51-101) and mining (NI 43-101) or the US SEC, that are legally enforceable.
- Accounting standards, such as those of the IASB or US FASB which may, by reference, be legally enforceable.
- Industry standards such as PRMS, COGEH, CRIRSCO, etc., may be referred to as standards to be followed in legislation.

PART E: THE STRUCTURE AND DYNAMICS OF THE RESOURCE SUPPLY SYSTEM

Part E discusses how the elements and concepts can be represented and analyzed as a system with interconnections and dependencies. There is considerably more to this topic than is given here.

17. THE STRUCTURE AND DYNAMICS OF THE RSS

17.1. INTRODUCTION

The previous sections have described the components of a resource supply system as if they existed in isolation. This is not the case, since they are linked in a network with many, sometimes hundreds or more, interconnected Nodes and Links that is far more complicated than a simple linear production-transport-processing progression.

An RSS consists of[43]:

- *Nodes*, with defined properties that carry out prescribed activities that can change over time.
- *Links* that carry information between Nodes, such as:
    - Quantity of resource
    - Financial (e.g., Current capital, Current value (NPV))
    - Pure information, such as into or out of a decision node or an analytic procedure (e.g., an NPV calculation).

As anyone who has seen oil, gas, or electricity distribution networks can attest, real world resource supply systems have many such nodes and links.

Creating an RSS model can be a major endeavour, but simple models may be useful in understanding and illustrating the properties of an RSS. Examining the complexities of a resource supply system network can be done in different but related ways, each of which provides a different perspective.

- Verbal descriptions are of value in defining a problem and can lay a foundation for other methods.
- Flow charts and System Information Models.
- Networks or Graphs.
- Agent based models (ABM) examine the actions and interactions of autonomous agents, such as operating companies, for their effects on a system.

17.2. FLOW CHARTS AND SYSTEM INFORMATION MODELS

Flow charts represent a sequential workflow or process with the various steps indicated by standard symbols[44] and their relationship joined by arrows indicating the direction of the flow of activity. Figure 7 below is a simple example, but they can be large and complex.

[43] The main terminology used here is *Network*, *Node* and *Link. Graph Science* (mathematics) uses the equivalent terms: *Graph Vertex* and *Edge.*

[44] Flowchart - Wikipedia Shows NIST standard symbols.

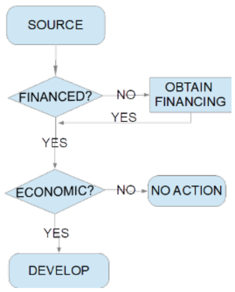

Figure 7. An example of a basic flowchart for a project.

A System information Model (SIM) is an essentially a sophisticated extension of a flow diagram and can be interactive, dynamic, and contain feedback loops.

17.3. NETWORKS

Flow charts and System Information models are typically used for project management but networks are better suited to represent the relationships of the many components that constitute an RSS and are the main focus of this report.

A network is a collection of nodes and links that represent relationships and have many applications (e.g., neural nets). Additional information may be found in the technical literature[45,46,47].

The links carry signals (information) that may be directed, indicated graphically in a network diagram, by arrowed lines showing the direction of information flow, or undirected without arrows. Links and nodes may be represented graphically by standard symbols. This is impractical for systems with many components and other representations, such as colours or shapes, may be used.

Nodes and links may be assigned "*Weights*"[48] which can be a deterministic value, or a stochastic function. For instance, the weight of a node could be the production rate or the result assigned by a decision rule, while the weight of a link could be a maximum transport capacity or the flow rate of funds.

The network of Figure 8 below is a simple resource supply system in which "Background" includes all extraneous contingencies (e.g., entitlement, environmental approvals, etc.). The arrows on the links indicate the direction of information flow.

[45] Newman, M. E. J., 2003. The Structure and function of complex networks. SIAM Review 45. Extensive references. http://www-personal.umich.edu/~mejn/courses/2004/cscs535/review.pdf
[46] Network science - Wikipedia
[47] Menczer, F. et al, A First Course in Network Science (book)
[48] Weighted network - Wikipedia

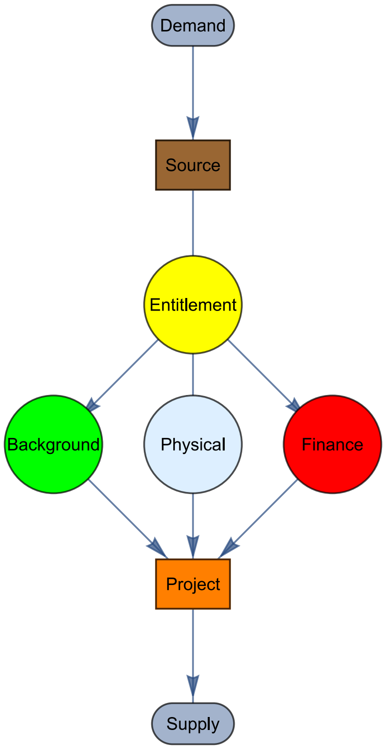

Figure 8. A simple RSS network.

More complete models can include:

- Many Source and Physical agent nodes.
- Several Finance nodes.
- Specific Background contingency nodes.
- Multiple links, such as several sources, transport routes with interconnections, different capacities, lengths, costs, etc. Natural gas pipeline and electrical supply systems are an example.
- Different Processing facility nodes with different costs and capacities.
- Stochastic capabilities.

Many nodes and links are static, with a fixed geographic location such as sources, pipelines and electricity grids, processing facilities. Others may be considered to have no formal locality although some may have a general geographical locality, such as finance from specific securities markets, or national regulatory and fiscal regimes.

The more complete, but still relatively simple conceptual network below has more than one node type and diverse links and is intended to provide a basis for thinking about an RSS. A real world RSS would be dynamic and more complicated would have many more components, with the properties of the nodes and links developed in detail.

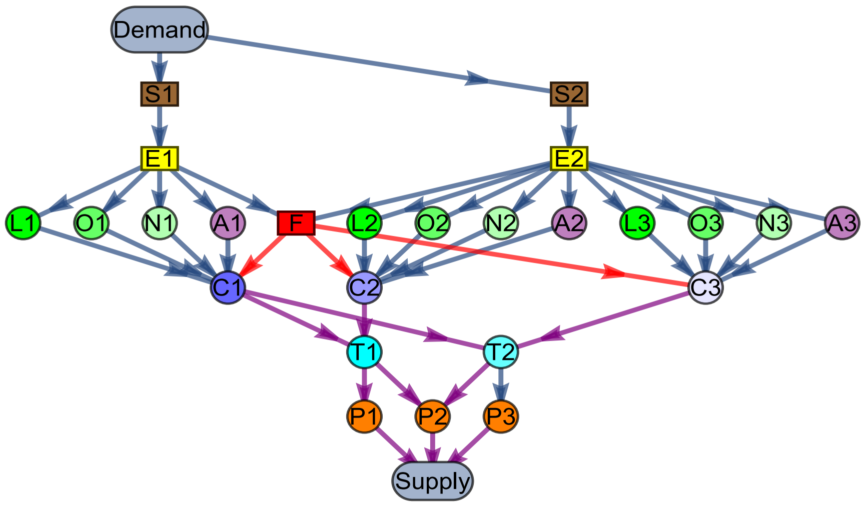

Figure 9. An illustrative network with multiple nodes and links.

Key to Figure 9

NODES

STAGE	SYMBOL	NUMBER	COLOUR	FEATURE EXAMPLES	DECISION RULE
Demand	Demand	1	Blue-Grey	Demand forecast: Quantity, price	Worth assessment?
Source	S	2	Brown	Characterisation: Quantity, quality	Potentially viable?
Entitlement	E	2	Yellow	Terms	Confirmed?
Financing	F	1	Red	Amount of loan	Confirmed?
Legal & Regulatory	L	3	Green Hues	Terms	Approved?
Social	O	3		Issues	Resolved?
Environmental	N	3		Issues	Resolved?
Political	A	3	Purple	Issues	Resolved?
Capture	C	3	Blue	Project assessment: forecast, Capex, Opex, timing, DRNPV, etc.	Viable?
Transport	T	2	Cyan	Available: quantity, transport capacity, costs etc.	Available?
Processing	P	3	Orange	Available: quantity, costs etc.	Available?
Supply	Supply	1	Blue-Grey	Contracts	Approved?

- All links carry information and may contain decision rules.
- Nodes contain information and decision rules.
- Red links carry information on financing.
- Purple links carry information on resource quantities.

A concept missing from Figure 9 is the assessment of viability that is carried out at almost every step (risk, discounted NPV, may be qualitative, etc.). Inclusion of an Assessment node and links would make it more realistic, but since every node would be connected with directed links to and from it, there would be so many links that the diagram would be unreadable and lose its illustrative nature.

Figure 9 is a static representation, a snapshot in time, but an RSS is a dynamic *Temporal network* with parameters changing over time. RSS networks may also be represented as *Multilayer or Multidimensional networks*[49] (see examples in Figure 10 below in which the different layers could represent different parameters, such as resource quantity, and financial value). Different layers are connected by links and influence each other.

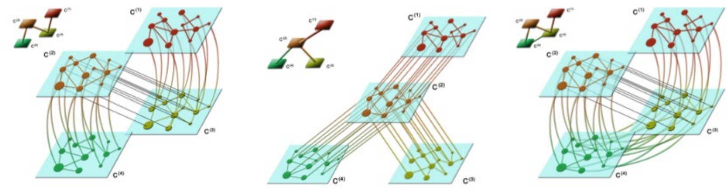

Figure 10. Three different multilayer networks with different structure in the network of layers.
Published under Wikipedia Commons licence. Previously published:
http://journals.aps.org/prx/abstract/10.1103/PhysRevX.3.041022
Author Dedalus1234

An RSS might be represented by a three-layer network with layers: quantity, finances, decision information and rules.

A complete RSS network may also consist of several smaller interconnected networks, a "network of networks". An example could be an oil pipeline system in a country that is connected to an international marine transport system.

17.4. THE RESOURCE SUPPLY SYSTEM AS A COMPLEX SYSTEM

A *Complex System* contains components that interact, for which the response to a change is typically non-linear and unpredictable. They have been extensively studied and a fuller description is beyond the scope of this report but further information can be found in the extensive technical literature[50].
They may:

- Exhibit the *"Butterfly effect",* a dependence in which a small change in initial conditions can result in large differences in a later state.
- Have *Emergent properties* that are not apparent from its components considered alone.
- Suffer from *Cascading failures* when a failure in one component ripples through the system causing failure of other components.
- Have *Critical transitions*, abrupt changes, in response to minor stimuli (possibly an extreme "Black Swan" event).

[49] Multidimensional network - Wikipedia
[50] https://en.wikipedia.org/wiki/Complex_system provides basic information and an extensive list of references. The Santa Fe Institute (which was established to study complex systems) has a large amount of information on its website https://www.santafe.edu/ and provides free on-line courses, notably the excellent Introduction to Complexity course.

The many interlinked and interdependent components of resource supply systems strongly suggests that they would display the characteristics of a complex system. The subcomponents of an RSS, such as a transport system, can be complex systems in their own right. This has significant implications for the ability to manage a resource supply system.

17.5. AGENT BASED MODELS

An *Agent-Based Model* (ABM)[51,52] simulates the dynamic actions and interactions of agents (located at nodes) in order to understand their collective behavior as a system, such as an RSS. When location is relevant, an ABM can be constructed in an *Environment* that consists of *Patches* with their own properties and can be 2D or 3D.

ABM has been implemented in computer programs, such as *Net Logo*[53], a powerful ABM software package that can be downloaded free from https://ccl.northwestern.edu/netlogo/.

The entire "space" of behaviours a model may exhibit can be explored in NetLogo using:

- *BehaviorSpace*, which runs a model many times, systematically varying the model's settings and watches what emerges from their interaction, a process sometimes called "parameter sweeping" (comparable to running Monte Carlo simulations).
- *System Dynamics Modeler*, in which populations of agents behave as a whole. It can be used to model material flows such as resources.

PART F: APPLICATIONS

Previous sections have described the elements and concepts that underlie the provision of the natural resources we rely on and it is suggested that they form a resource supply system with the characteristics of complexity, such as non-linearity, that are typical of such systems. Some potential applications are briefly touched on here.

18. APPLICATIONS OF RESOURCE MANAGEMENT AS A SYSTEM

18.1. INTRODUCTION

[51] Agent-based model - Wikipedia,

[52] Wilensky, U., Rand, W., 2015. An Introduction to Agent Based Modelling. MIT (Book)

[53] NetLogo is a free ABM program that can be downloaded from https://ccl.northwestern.edu/netlogo/ . It contains a Models Library with many examples that can be used to examine the behaviour of complex systems. The Santa FE Institute provides a short Tutorial and a longer course on NetLogo.

This report provides a large scale generic map of an RSS. The elements and concepts may be regarded as the ”bones” from which a “skeleton” (network) of an RSS may be constructed for various purposes. Once a network has been constructed, it would need to be populated with information, decision rules, etc., for analysis.

Although there are practical limitations to the parameters that can be included in a study of a resource supply system, it should include those that are needed for it to be representative of the objective of problem under consideration. It should be “fit for purpose.”

Creating a detailed realistic network RSS model would be a major endeavour but simpler conceptual models may be useful in understanding and illustrating the properties of an RSS. Like conventional maps an RSS can be drawn at different scales, to show greater or lesser detail, to show different features (e.g., specific quantity flows, tracking CO_2 emissions or other environmental factors, etc.) or to examine behavioral dynamics or aspects. Every RSS model is a snapshot at a point in time, but it is dynamic, and changes with the flow of information.

18.2. CONSTRUCTING A MODEL

Simple flowcharts and networks can be constructed with pencil and paper and but even moderately complicated models require computer programs[54]. Points to consider:

- What is the objective? This may be straightforward but could be an experimental “what if?” exercise.
- What is the ROD? The same model may be assessed under several different RODs.
- What level of detail and acceptable uncertainty is needed to satisfy the objective? For instance, if there are many sources, it may be adequate to consider only the few that provide most, say 80% of supply.
- What are the decision rules?
- Nodes and links can be modelled as:
    - Deterministic: simple but this would not account for the consequences of the uncertainty of many of the important parameters.
    - Stochastic: more difficult to construct and model but more realistic and informative.

- Models may be:
    - Conceptual, designed to examine the behaviour of an RSS and even a simple model can exhibit complex behaviour. As the details in a conceptual model increase, it may approach a:
    - Realistic model, an unattainable ideal, and unnecessary for most purposes, but it should be able to meet an objective.

[54] The network of Figure 9 was constructed using Mathematica (Wolfram Mathematica: Modern Technical Computing). A free Python system is NetworkX (networkx - Search (bing.com)).

18.3. ANALYSING MODELS

There is an extensive literature on the analysis of networks and complex systems, some of which is cited in the list of references. A detailed discussion of possible applications is beyond the scope of this report, but they might include:

- Providing a holistic view of the resource supply system for discussions, debates, and decisions.
- Just constructing a model of an RSS can be instructive and lead to an improved understanding of resource supply.
- Providing an educational framework on the process of providing resources.
- Developing an information framework for resource supply.
- Tracking the movement of resource quantities, money, and values, etc., possibly using a blockchain if the data is available.
- Analysing the impact of perturbations to an RSS, e.g., what is the impact of a two year delay in project construction, shortfall in source rate or quality, extreme events, failure of some links or nodes, etc.
- Examining the nature of a transition to complexity as an RSS increases in size or complexity. Is it gradual or abrupt at a threshold? Is it "manageable"?
- How do you develop a robust system?
- Management of resource supply, including timing and life cycle, costs, constraints, impediments, etc. Could be integrated with approaches such as Program Evaluation and Review Technique[55] (PERT) and Critical Path Method[56] (CPM).
- Manage resource production in an eco-friendly way. Define the value chain and weak links that impact social and environmental issues.
- Integrating the resource supply system into the circular economy (recycling, use, and reuse, etc.)
- Building RSS models to examine issues for specific resource types.

This is neither an exhaustive list nor an in depth account of potential applications.

18.4. FURTHER WORK

This report has focused on identifying the fundamental elements of an RSS and how they can be combined into a network for further analysis that may be done as an Agent Based Model. Further work might be to develop network concepts and ABMs. This might include:

- Exploring the best structure for an RSS network: monolayer or multilayer.
- Developing a structure and format for decision rules.
- Developing the functions to be used as weights.

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[55] Program evaluation and review technique - Wikipedia

[56] Critical path method - Wikipedia

- Deciding on the best approach to assigning weights to links and nodes: list (like a vector), matrix, etc.
- Integrating the computational and graphic display capabilities of Mathematica and NetLogo to build an ABM.

GLOSSARY

"When I use a word,' Humpty Dumpty said in rather a scornful tone, 'it means just what I choose it to mean — neither more nor less.'
'The question is,' said Alice, 'whether you can make words mean so many different things.'
'The question is,' said Humpty Dumpty, 'which is to be master — that's all."

Lewis Carroll, in "Alice through the Looking Glass"

A clear understanding of terms is important and this glossary contains information on words as they are used in this report. This may not be identical to the way they are used elsewhere.

- Acronyms
- Definitions for this report, indicated by a (D).
- Examples, explanation, discussion, and references and other material, to support the use and understanding of the definitions. These are shown in a lower case font (9 point Calibri) and should not be confused with the definitions.

Sources

Some of these have been derived from other publications without change or slightly edited, in which case the original source has been indicated, when known.
Useful general sources of definitions are in the UNFC, PRMS, COGEH, CRIRSCO.

Acronyms

EGRM Expert Group for Resource Management
COGEH Canadian Oil and Gas Handbook
CRIRSCO Committee for Mineral Reserves International Reporting Standards
CSA Canadian Security Administrators
FASB Financial Standards Accounting Board (USA)
HWES Human World Economic System
IASB International Accounting Standards Board
IEA International Energy Agency
NPV Net Present Value
DNPV Discounted Net Present Value
RDNPV Risked Discounted Net Present Value
ROTR Resources Other Than Reserves
ROD Realm of Discourse
RSS Resource Supply System
SEC US Security Exchange Commission
SPEE Society of Petroleum Evaluation Engineers
SPE Society of Petroleum Engineers

UNECE United Nation Economic Commission for Europe
UNFC   United Nations Framework Classification System for Resources

Definitions, explanations, discussions

Action. Something done by an agent, typically to achieve an objective.
Not necessarily physical, may include financing for instance.

Agent (D). An autonomous entity with defined properties that carries out prescribed activities.
Used in Agent Based Modelling to represent many types of entity and may be individual (e.g., a company or government) or collective set (e.g., a combination of several companies or governmental organisations). The properties and behaviour of an agent can change over time as it reacts to information that it receives from other agents and the environment. Examples of agents include:

- A Funding agent, such as a bank or securities market, that provides the funds for an operator's activities.
- An Operating agent, a company or group of companies that explores for a mineral, mines, purchases. other companies, sells products, etc.
- A Transport or Processing agent.

Agent Based Modelling (ABM) Computational models that simulate the actions and interactions of autonomous agents (both individual and collective entities) with a view to assessing their effects on the system as a whole. (Wikipedia, edited)

Assessment (D) is the process of analysing a resource for a specific purpose.
It is based on a resource **Characterisation** supplemented by additional information and financial analysis.
It is typically carried out to assist in an investment decision and should be at a level of detail needed, i.e., "fit for purpose".

Background (D). A collection of contingencies, mostly extrinsic and beyond the control of a project operator, that must be satisfied for a project to proceed.
They include:
Legal issues such as entitlement
Regulatory processes
Political issues
Environmental and social issues
Social licence

May also be called a framework, milieu, or environment.

Black Swan. Colloquial term for an unexpected, low probability, extreme event, with significant consequences, usually recognized a posteriori.
Usually recognised a posteriori.

Butterfly Effect. See **Complex System**.

Canadian Oil and Gas Evaluation Handbook (COGEH). Provides extensive guidance on the evaluation and classification of oil and gas resources. It refers to the PRMS for the classification standard but differs occasionally on guidance.

Is the standard for securities reporting in Canada. First edition in 2002, with periodic updates. The current edition is available from COGE Handbook Subscription - Society of Petroleum Evaluation Engineers Canada (speecanada.org)

Canadian Securities Administrator (CSA). Canadian regulatory body that governs securities disclosure.
See Canadian Securities Administrators | Who we are | Overview (securities-administrators.ca)

Cascading change. See **Complex System**

Chance of Commerciality is the probability of attaining commerciality, expressed quantitatively or qualitatively.
See the PRMS for further explanation.

Characterisation (D). A description of a resource source.
It can range in scope and quality, from limited to comprehensive and may provide the basis of an assessment for an investment decision.

Circular economy See Circular economy - Wikipedia

Classification (D). A procedure that assigns the estimate of a recoverable or potentially recoverable resource quantity to a defined Class (and sometimes also to a Category that describes the associated uncertainty).
There are several such systems, such as the UNFC, PRMS, CRIRSCO, those of Russia and China; financial authorities may also have their own systems.

Although resource classification provides valuable information, it is only a part of what is required for a decision and only provides information at a point in time, while **Resource Supply Management** is a dynamic process.

For a population, whose members each belong to one of different sets or classes, a classification rule or classifier is a procedure by which the elements of the population set are each predicted to belong to one of the classes. A perfect classification is one for which every element in the population is assigned to the class it really belongs to. An imperfect classification is one in which some errors appear, and then statistical analysis must be applied to analyse the classification.

More formally, given a data set consisting of pairs *x* and *y*, where *x* denotes an element of the population or sample and *y* the class it belongs to, a classification rule *h*(*x*) is a function that assigns each element *x* to a predicted class $\hat{y} = h(x)$. Where $\hat{y}$ represents an approximation. (Based on Wikipedia https://en.wikipedia.org/wiki/Classification_rule)

Commodity. A general term to describe a good or service used in a transaction, usually commercial. It may be for an end use (e.g., food) or used in the creation of other goods or services.
The term Product as used for an RSS is a subset of Commodity.

Complex system. A system with many components that may interact and display behaviours not readily predictable from the properties of the individual components.
Response to a change is typically non-linear and unpredictable and it may:

- Exhibit the B**utterfly Effect**, a dependence in which a small change in initial conditions can result in large differences in a later state.
- Have **Emergent** properties that are not apparent from its components considered alone.
- Suffer from **Cascading Failures** when a failure in one component ripples through the system causing failure of other components.
- Have **Critical Transitions**, abrupt changes in behaviour in response to minor stimuli.

Commerciality. The status of a resource supply project with respect to the relevant contingencies.
An RSS that has satisfied all contingences has the capability to deliver a final product to a user.

Committee for Mineral Reserves International Reporting Standards (CRIRSCO). Technical standards for mineral reserves reporting. See [CRIRSCO (cim.org)]

Concept (D). The underlying ideas behind the assessment of resources, including information, time value of money, etc.

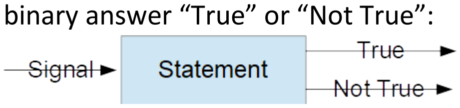
Contingency (D). A specific criterion or condition that must be satisfied before a project can proceed.

Critical transition or change See Complex system.

Cut-off (D). A value that separates parameters based on a specified criterion.
Examples:
Separates viable projects with an NPV that is greater than zero from non-viable projects with an NPV of less than zero at a desired rate of return.
A cut off value of > 5% porosity for pay in a gas reservoir where rock of < 5% porosity is not expected to contribute to flow into a borehole.

Decision Gate (D). A node, that contains one or more decision rules.
An input link provides information to a Decision gate in the form of a signal and an output link conveys a decision to subsequent stages of a resource supply system.

Decision Rule (D). A statement that can be tested against the information in a decision Gate to provide a binary answer "True" or "Not True":



Typically to resolve a contingency. Usually binary but may be multidimensional.

Demand (D). The expression of a user's desire and ability to acquire a product.
May relate to a product or aggregate endowment for resources, a quantity. The basic force that drives economic activity.

Economic Analysis See **Evaluation**

Economic Viability. See Viability

Economic Limit. The rate below which resource production is not economically viable.

Edge connects **Vertices** in a network.
Terminology used in network science, equivalent to **Link.** May be assigned a **Weight** that operates on the information that it carries.

Element (D). A fundamental constituent of a resource supply system.
The informal term Component may refer to elements but also to other constituents of a resource supply system and

Entitlement. The legal right to produce and sell a resource.

Environment

a. The physical, chemical, and biological milieu in which an RSS operates.
b. The 2 or 3D space of Agent Based Modelling, in which agents operate, divided into **Patches** that can have and change their properties, and interact with agents.

Environmental (D). The physical, chemical, and biological impact on, or changes to, the surrounding pre-existing environment, due to a project.
E.g., heavy metal contamination in soils or water, disruption of wildlife habits and migration characters, etc. May have societal consequences, see Social.

Evaluation provides an estimate of the quantity and, usually, a monetary value of a recoverable resource.

Exploration. Search for and identification of a resource source.
Typically used for non-renewable resources, but conceptually applies to renewable resources.

Externality. A cost or benefit that affects a party who did not choose to incur that cost or benefit.

Extraction. The process of separating a desired product from its' source.
Typically applied to material resources but could apply in principle to renewable sources such a solar energy.

Financing. The provision of finances for resource activities.

Financial reporting. Reporting of the financial and related information on resource activities, usually according to prescribed standards.
Typically, also includes quantity estimates. The standards include those of the US Securities Exchange Commission (SEC), The Canadian Securities Administrators (CSA), the International Accounting Standards Board (IASB), and others.

Geothermal energy. Subsurface heat that may be tapped as an energy source.

Human World Economic System (HWES). The worldwide economic system of which the Resource Supply System is part.

Information. Knowledge derived from analysis.
The concept of information is well developed, and a more in-depth explanation and many references may be found in Information - Wikipedia.

Internality. A cost or benefit that affects a participant in a project.

Inventory. a data depository of Identified (**Known**) and **Unidentified (Unknown) Sources**

Lead. A potential resource within a play that requires more data acquisition and/or evaluation to be classified as a prospect.
See Play, Prospect

Legal contingency. A background contingency established by a statutory body such as a government.
For a resource supply system, this includes entitlement and the conditions under which a resource supply activity operates. See also **Regulation**.

Lever. An informal name for an action that may be taken to create an anticipated change in the behaviour of a resource supply system.

Link Connects Nodes in an ABM.
The same as network **Edge**. May be assigned a **Weight** that operates on the information that it carries.

Market. A venue for the sale and purchase of products of a resource supply system.
The final sales point at the exit point of the Resource Supply System, Supply.
See https://en.wikipedia.org/wiki/Market_(economics) for a more thorough discussion of markets.

Mineral. A naturally occurring sub-surface material. Generally used for solid organics, but also used for fluids such as oil and gas.

Multilayer or Multidimensional Network. Network in which different layers represent different parameters, such as resource quantity, and financial value and are connected by links.

Natural resource. A resource that is of natural occurrence.

NetLogo. A powerful, free, ABM system
See What is NetLogo? at NetLogo Home Page (northwestern.edu) (1999). http://ccl.northwestern.edu/netlogo/.

Network. Graph or system formed by interconnected Nodes and Links.
May be represented graphically or by an adjacency or incidence matrix. See also Temporal network and Multilayer or Multidimensional network.

Node. A connection point in a network.
May be of different types: Agent, Decision Gate, etc. The same as a network Vertex. May be assigned a **Weight** that operates on the information that it carries.

Operator. An **Agent** that carries out an activity related to resource supply.

Patch (ABM). A 2 or 3-D spatial component of a NetLogo environment with assigned properties, in which Agents operate and interact.

Petroleum. Naturally occurring hydrocarbons, may be gas, liquid, or solid.

Petroleum Resource Management System (PRMS). Petroleum resource classification and guidelines system. Petroleum Reserves and Resources Definitions (spe.org)

Physical System. The physical activities required to produce, transport, process, and deliver a Final Product to a user.

Play. A bounded geographical area or geological volume that may contain unidentified resources.
See Lead, Play.

Political (D). Action by a controlling organization such as a government, that may influence, impede, prevent, or facilitate the ability to proceed with a project.

Price. The monetary value of a good, service or resource established during a transaction.
https://www.economicsonline.co.uk/Definitions/Price.html.)

Prospect. A potential resource within a play that is sufficiently well defined to be a viable target for a project.
See Lead, Prospect

Present Value (PV). The value today of a sum of money that will be received in the future in contrast to some future value it will have when it has been invested at compound interest.

- **NPV** Net Present Value
- **RDNPV** Risked Discounted Net Present Value

Probability. The chance that an event A will occur within an interval, $0 \leq$ Probability of event A ≤ 1.
May be expressed qualitatively or quantitatively.

Processing (D). Physical, chemical, electrical, or other, treatment that separates a desired product from undesired material that remains as residue or waste.
Although energy may be generated at the location of a source, and a few materials may be used directly without processing (e.g., coal, some natural gas), most materials require processing, sometimes in several intermediate stages to provide a final product.

Product (D). A material or energy that is produced during an RSS process.
It may be material (e.g., copper, oil, etc.) or energy and is created by processing sourced material or energy and may subsequently be used in the manufacture of other goods.

- **Intermediate Product (D)**. A product that is produced in an RSS at a point before the creation of the product desired by a user.
- **Final Product (D).** The product desired by and provided to a user.
- **By-product (D).** A secondary product with commercial value produced by an RSS process.
  Examples:
  Sulphur extracted from sour natural gas for which the prime objective is gasses of the alkane series.
  Condensate liquids produced during oil and gas production.

Project (D). A defined activity or set of activities that is directed towards the supply of a product.

Quantity. A general term to describe a mineral volume, weight, or a measure of energy.

Quality. The ratio between the quantity of a product and the quantity of the source in which it is contained.

Realm of Discourse (ROD) (D). Describes the conditions, context, and the reason for examining, evaluating, or classifying, a resource or a resource supply system.

Recovery. A general term for the extraction of a product from its source.

Recovery factor. The proportion of a naturally occurring resource that may be recovered as a product.

Recycling. Recovery of a product from waste created during previous activities and from discarded products.

Regulation. The rules, and directives for carrying out the intent of **Legislation**.

Reporting. The conveyance of information to a user for a specific purpose.
The scope will range from summary to comprehensive, and should be “fit for purpose”, depending on the needs of a user.

Residue. Analogous to Waste.

Resource. A general term for the quantity of a useable commodity that includes both an original material or energy source and a produced and processed material product or energy that can be accessed for use. (See also Natural resource).

Resource supply management (D). An active process that attempts to provide the timely and efficient supply of a required final product quantity to users.

Resource supply system (RSS) (D). The set of physical, financial, economic, and **Background** activities that are carried out to provide a final product.

Resource type. The form of a resource, material, or energy.

Risk (D). The probability that a project fails to meet a defined objective of a project.

Sales Point. Location of ownership transfer of a product.

Storage (D). Used when storage of an Intermediate or Final product is a fundamental part of a project.

Scenario (D). Describes the specific details, activities, and conditions under which a project is evaluated, such as timing of activities, forecasting production rates, and costs.
The same project may be assessed under several scenarios.

Securities Exchange Commission (SEC). The USA Federal agency responsible for protecting investors, maintaining fair and orderly functioning of the securities markets, and facilitating capital formation.

Signal. A function that conveys information about a phenomenon. *Wikipedia*
The information can be of many types and in many forms, digital or analog, probabilistic, or deterministic.

Social (D). The impact on humans and society, of environmental changes including:

- The effects of environmental changes
  e.g., health issues due to heavy metal contamination.
- Changes in social systems and structures.
  e.g., ownership claims, traditional land usage, land and other value changes, changes in local population community structures, the creation of jobs and economic activity, etc.).

Social licence or **Social Licence to Operate (SLO**). A “portmanteau” phrase that is often used to describe a collection of social and environment issues related to a project.
It is colloquially useful for this purpose, but there may not be agreement on what the relevant issues are for a project, and they are likely to be differences.

Society a general term used here to describe the worldwide community of humans.

Solar energy. Energy harvested from sunlight.

Source (D). The origin of a resource quantity before it is produced into an RSS process and the feedstock for resource projects from which products can be developed.
Sources may be in their natural or secondary forms (anthropogenic sources, tailings, etc.).
Often referred to as "in situ" or "in place" for a material source and usually including a geographic location.
It includes bioenergy, geothermal, hydro-marine, solar, wind, injection for storage, hydrocarbons, minerals, nuclear fuels, and water.

- **Unknown source (D)**. A source that may be thought to exist but not yet identified.
  May also be described as "Unidentified" or "Undiscovered" the potentially recoverable portion of which can be classified as a "Prospective resource".
- **Known source (D)**. A source that has been identified and considered to have the potential to yield a resource.
- **Endowment source (D)** is the total of the individual sources in a region.
  Typically used by a national agency such as a geological survey, to estimate the quantity of a resource within national boundary.
- **Project source (D)** is a source, or the sources attributed to a project.

Subjective Probability. Probabilities assigned on the basis of personal belief and the information available. Sophisticated approaches such as Delphi may be used.

Supply (D). The quantity of a Final Product delivered to a User.

System. A set of linked individual components such as an RSS.

Temporal Network. A network for which the parameters change over time (such as an RSS).

United Nations Framework Classification for Resources (UNFC).
See [UNFC_ES61_Update_2019.pdf (unece.org)]

User (D). A person or organisation that accepts a product at an intermediate or final point along a supply chain.

Valuation (D). An estimate of financial value such as Net Present Value.

Vertex. A connection point in a **Network**.
The same as a network **Node**. May be assigned a **Weight** that operates on the information that it carries.

Viability. The practical feasibility of carrying out a resource supply activity.
This requires that all relevant contingencies, including economics, are satisfied.

- **Project viability**. The viability of a specific project.
- **Aggregate (System) viability**. The viability a system of projects to provide supply of resource.
  This does not require the viability of all the projects that make up a system, but that the system provides this capability.
- **Economic Viability.** Measure of the financial viability of a project typically as an NPV.
  Even though economically viable, a project may not be viable for other reasons.

Waste. The **Residue** with no commercial value that remains when a product is extracted from a source.
May subsequently determined to be a source, leading to recycling.

Weight. A function assigned to a **Node** or **Link** that operates on the information that it contains or is passed along it.
This may be a material quantity such as a maximum capacity, a function, or pure information such as a probability.

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