System of Environmental Economic Accounting

SEEA Central Framework 2028 update

Draft Guidance Note

Issue D8

Treatment of the Atmosphere as an Asset

Prepared by Robert Smith
Version 2 for TC Meeting of September 2026: 24.08.2026

Executive Summary

Description of the issue

The SEEA CF does not currently include the atmosphere as an environmental asset, citing that their stocks are too large to be meaningful for analytical purposes. However, it was included in the SEEA 2003 as an asset and was considered for inclusion as an asset during the revision of the SEEA EA. Further work is needed to articulate how the atmosphere and its functions may be appropriately characterised in accounting terms. This work should consider how transactions related to the atmosphere, for example transactions related to reducing greenhouse gas emissions, are most appropriately recorded. Research on this topic must link to related work in the context of the SEEA EA and the SNA.

Summary of proposals

First, we draw a distinction between, on the one hand, the atmosphere itself, which comprises the various gases and other matter plus the energy contained in them found in various layers between the surface of the planet and outer space and, other the other hand, the space above the planet's surface that is occupied by the atmosphere and by other matter (e.g., air- and space-craft); we refer to this space as V-space (for "vertical" space).

Based on review of existing research and existing material, we find four issues potentially requiring treatment regarding the atmosphere itself and the V-space it occupies:

- **Issue 1**—Inclusion of the atmosphere in the revised SEEA-CF asset boundary
- **Issue 2**—Inclusion of V-space in the revised SEEA-CF asset boundary
- **Issue 3**—Inclusion of radio spectra in the the revised SEEA-CF asset boundary
- **Issue 4**—Treatment of permits to emit pollutants in the revised SEEA-CF

On Issue 1, we find no basis for expanding the SEEA-CF asset boundary to include the atmosphere itself as there is no meaningful basis for measuring the entire atmosphere or any of its of its material components in physical or monetary terms; they are effectively unchanging in physical terms and freely available to all who wish to use them and, so, are free. As for the energy benefits of the atmosphere (wind energy and heat)—which *are* amenable to both physical and monetary measurement—there is no justification for adding the atmosphere to the asset boundary to measure these since they are equivalent to the renewable wind and heat energy assets that we assume will be added to the revised SEEA-CF asset classification (as per the recommendation in Guidance Note A9.3).

On Issue 2, we find there *is* a basis for enhanced recognition of V-space as an asset. We say "enhanced" recognition because, in fact, V-space has long been recognized as part of the land asset in both the SNA and the SEEA-CF, though it has received little attention. The SEEA-CF, for example, defines land (para 2.121) as the area "under effective control of a single government…including islands, *airspace*, territorial waters and territorial enclaves" (emphasis added). We find that airspace (or V-space as we call it in this note) is economically important enough that consideration should be given to recognizing it more explicitly in the in the revised asset classification. We propose three options for doing so, including the option of continuing with the existing treatment of including V-space as part of the land asset. These

three options are summarized below and presented in Table 1 for greater clarity, with proposed changes shown in green.

- **Option 2a**—Make no change to the SEEA-CF environmental asset classification, leaving V-space as an implicit component of land and the associated freshwater and marine areas.
- **Option 2b**—Add a new asset called "Space above land" to the SEEA-CF classification, following land in the classification.
- **Option 2c**—Add a new asset call "Space" to the SEEA-CF classification in place of the current land asset, with two sub-categories beneath it, one for "Space on land" and the other for "Space above land".

Table 1 - Options for classification of V-space in revised SEEA-CF[1]

Option 2a (existing)	**Option 2b**	**Option 2c**
1.Mineral and energy resources	1.Mineral and energy resources	1.Mineral and energy resources
2. Land	2. Land	*2. Space*
3. Soil resources	*3. Space above land*	*2.1 Space on land*
4. Timber resources	4. Soil resources	*2.2 Space above land*
5. Aquatic resources	5. Timber resources	3. Soil resources
6. Other biological resources	6. Aquatic resources	4. Timber resources
7. Water resources	7. Other biological resources	5. Aquatic resources
	8. Water resources	6. Other biological resources
		7. Water resources

On Issue 3, we note 1) that the SNA treats radio spectra as a natural resource asset while the SEEA-CF does not and 2) that radio waves make use of V-space for propagation (though, unlike sound waves, radio waves do not require the atmosphere itself for propagation). Since the spectrum is economically valuable and reflects a use of the V-space asset that is already implicitly recognized in the SEEA-CF, continued exclusion of radio spectra from the SEEA-CF asset boundary is unjustified. We consider three possibilities for adding the radio spectrum to the SEEA-CF asset classification: 1) the radio spectrum itself is the asset that is scarce and from which the value arises; 2) V-space is the source of this scarcity; 3) both the radio spectrum and V-space are scarce and therefore both are assets to be recognized. These three possibilities lead, in turn, to three accounting options that are summarized below and presented in Table 2, with proposed changes shown in green.

- **Option 3a**—Include "Radio spectra" in the environmental asset boundary of the revised SEEA-CF in a manner fully in keeping with its treatment in the SNA 2025; that is, as an asset unto itself from which all asset value arises.

[1] Sub-categories under assets for which no changes are proposed are not shown for the sake of brevity.

- **Option 3b**—Include "Space for radio wave propagation" as a sub-entry under a new asset called "Space above land" in the asset classification. This reflects the view that it is V-space that is scarce and is consistent with Option 2b above.
- **Option 3b_alt**—An alternative version of Option 3b is to add "Space for radio wave propagation" but as a sub-sub-entry under a new asset called "Space", which is consistent with Option 2c above.
- **Option 3c—**Include both a new entry in the classification for "Space above land" with a sub-entry for "Space for radio wave propagation" plus a new entry for "Radio spectra", on the grounds that both these are scarce and that, therefore, asset value arises from both of them. This is consistent with Option 2b above.
- **Option 3c_alt:** An alternative version of Option 3c is to add "Space for radio wave propagation" but as a sub-sub-entry under a new asset called "Space", consistent with Option 2c above and also to add a new entry for "Radio spectra".

Table 2 - Options for classification of the radio spectrum in revised SEEA-CF[2]

Option 3a	**Option 3b**	**Option 3b_alt**
1.Mineral and energy resources	1.Mineral and energy resources	1.Mineral and energy resources
2. Land	2. Land	*2. Space*
3. Soil resources	*3. Space above land*	*2.1 Space on land*
4. Timber resources	*3.1 Space for radio wave propagation*	*2.2 Space above land*
5. Aquatic resources	4. Soil resources	*2.2.1 Space for radio wave propagation*
6. Other biological resources	5. Timber resources	3. Soil resources
7. Water resources	6. Aquatic resources	4. Timber resources
8. Radio spectra	7. Other biological resources	5. Aquatic resources
	8. Water resources	6. Other biological resources
		7. Water resources
Option 3c	**Option 3c_alt**	
1.Mineral and energy resources	1.Mineral and energy resources	
2. Land	*2. Space*	
3. Space above land	*2.1 Space on land*	
3.1 Space for radio wave propagation	*2.2 Space above land*	
4. Soil resources	*2.2.1 Space for radio wave propagation*	
5. Timber resources	3. Soil resources	

[2] Sub-categories under assets for which no changes are proposed are not shown for the sake of brevity.

6. Aquatic resources	4. Timber resources	
7. Other biological resources	5. Aquatic resources	
8. Water resources	6. Other biological resources	
9. Radio spectra	7. Water resources	
	8. Radio Spectra	

Finally, on issue 4 we find that two economic interpretations of permits to emit pollutants are possible. On the one hand, they can be understood as Pigouvian taxes and on the other they can be seen as rights use V-space as a sink. This leads to the following three accounting options:

- **Option 4a—**Leave the treatment of emission permits unchanged, keeping it aligned with the SNA 2025. This would mean that cost of the permits would continue to be recorded as a tax on production. The implicit assumption behind this is that emission permits are intended by governments to operate as forms of Pigouvian taxes intended to internalize the externalities associated with excess emissions.
- **Option 4b—**Treat emission permits as payments for the rights to use an explicit V-space asset ("Space above land") as a pollutant sink, which would imply that they are a form of asset rental rather than payment of a tax. This option would correspond to selecting Option 2b above regarding the classification of V-space and would mean that the SEEA-CF's would not be aligned with the SNA 2025 on this issue, noting that the treatment of emission permits in the SEEA CF is directly discussed in Guidance Note A9.2.
- **Option 4b_alt—**An alternative version of Option 4b (reflecting Option 2a above) is to not add an explicit asset for V-space to the classification, but to treat emission permits as payments for the rights to use the existing Land asset, recognizing that this asset includes V-space.

Questions for global consultation

1. Do you agree with the distinction made between the atmosphere and V-space in this Guidance Note?
2. Do you agree that there are no grounds for recognition of the atmosphere itself as an environmental asset in the revised SEEA-CF (Issue 1)?
3. Which of the proposed treatments of V-space as an asset (Issue 2) do you agree with?
4. Which of the proposed treatments of the radio spectrum (Issue 3) do you agree with?
5. Which of the proposed treatments of permits to emit pollutants (Issue 4) do you agree with?

Additional questions for September 2026 TC meeting

1. Do you agree with the conclusion in para 61 that even if the SEEA-CF does not say so explicitly its intention is that components of the environment recognized as environmental assets should lend themselves to measurement in both physical and monetary terms?
2. Do you agree with the contention in para 68 that the relevant benefits recognized in the SEEA-CF as the basis for identifying assets should be expanded from just material- and space-related benefits to also included energy-related benefits?

Table of Contents

1 Introduction

1. The United Nations Statistical Commission has endorsed the update of the SEEA 2012 Central Framework and work in underway on the update process. An initial task is establishing a clear scope for the issues that have been identified to be the focus for the update. This guidance note provides a description of **Issue D3 – Treatment of the Atmosphere as an Asset** to support a common understanding of the work that will be needed to fully investigate and articulate the alternative approaches and recommendations for change or addition to the SEEA Central Framework.

1.1 Motivation for the proposed change

2. The short description of issue D8 "Treatment of the Atmosphere as an asset" as proposed in October 2024 by the UNCEEA's Technical Committee on the SEEA Central Framework is:

    - "The SEEA CF does not currently include the atmosphere as an environmental asset, citing that their stocks are too large to be meaningful for analytical purposes. However, it was included in the SEEA 2003 as an asset and was considered for inclusion as an asset during the revision of the SEEA EA (in the end, the SEEA EA only includes the atmosphere directly above and within an ecosystem as an integral part of the ecosystem asset). Further work is needed to articulate how the atmosphere and its functions may be appropriately characterised in accounting terms. This work should consider how transactions related to the atmosphere, for example transactions related to reducing greenhouse gas emissions, are most appropriately recorded. Research on this topic must link to related work in the context of the SEEA EA and the SNA."

3. The short description above provides a concise summary of the past discussion and current treatment of the atmosphere in the SEEA. The recent update of the SNA did not provide additional guidance on this issue, but the topic is included in the research agenda noting the relevance of "measuring the value of depleting the atmosphere by using it as a sink".

4. While the atmosphere is not treated as a distinct asset in the SEEA Central Framework (SEEA CF), flows to the atmosphere, in particular air emissions, are recorded in physical supply and use tables within the general category of flows to the environment. The discussion under this issue is therefore not a question of whether flows to and from the environment should be recorded, but rather whether the atmosphere should be treated, for accounting purposes, as a distinct asset.

1.2 Structure

5. The remainder of this Guidance Note proceeds as follows. Section 2 reviews the existing scientific understanding of the atmosphere and the related existing accounting guidance in the SEEA-CF, the SEEA 2003, the SEEA-EA and the SNA 2025. Based on the material presented in Section 2, Section 3 addresses the merit of considering the atmosphere as an environmental asset and considers the possibilities for its measurement in physical and monetary terms. Section 4 offers recommendations regarding the proposed treatment options, finishing with a list of questions to reviewers regarding the recommended options. Section 5 presents our recommended accounting options and notes connections with and potential implications for other issues being considered in the update process.

2 Review of existing research and accounting guidance

2.1 What is the atmosphere?

6. Deciding whether the atmosphere could be considered an environmental asset first requires an understanding of what the atmosphere is in physical terms. We provide a brief description below, drawn mainly from the University Corporation for Atmospheric Research's online overview. Before doing so, however, it is worth emphasizing that that the atmosphere is to be understood as a *dynamic global system* interconnected with other global systems and not as a *static, isolated stock of gaseous matter*. The atmosphere is in constant flux in terms of its energy content, its physical extent above the planet's surface and its chemical composition. It is also in constant interaction with other global systems (oceans, soil, water, forests, etc.), exchanging materials and energy with them in a variety of forms and through a variety of processes.

7. A second essential point is that the *atmosphere* should not be confused with the *space* it occupies above the planet's surface. The atmosphere is properly thought of as the gaseous, liquid and solid matter (and associated energy) that fills this space, forming several physically distinct layers that extend some 190,000 kilometres into space (after which true outer space begins). The space occupied by the atmosphere is, then, quite simply just the space existing between the earth's surface and the outer reaches of the atmosphere. For simplicity, **we call this space "V-space**" (for "vertical space") here.[3] We distinguish it from the space occupied by land and water on planet itself, which we call H-space (for "horizontal space").

8. There is, in some sense, competition between humans and the atmosphere (as an environmental system) for "use" of V-space—not to mention competition for it between humans (two airline companies competing for landing rights at a busy airport, for example). In other words, V-space is scarce and in high demand. Humans use V-space for numerous purposes vital to economic activity: aircraft and spacecraft fly or orbit in and through it; human-produced electromagnetic (radio) waves of various sorts travel through it; and it serves as a "dumping ground" or sink for massive amounts of waste materials and energy from human activities. These activities, it must be emphasized, are not uses of the atmosphere itself[4], but of V-space.[5]

9. The above raises the possibility that there are actually two resources that might be recognized as assets in the revised SEEA-CF: the atmosphere itself and the V-space that it occupies. This dual treatment is essentially the same as the already-accepted treatment of the H-space occupied by land and the other features of the planet's surface (such as timber or soil resources) as distinct assets in the SEEA-CF (see, for example, para 5.10 and para 5.20). In the remainder of this Guidance Note, we approach the topic at hand

[3] We choose not to use the more familiar term "airspace", as this risks confounding of air with the space it occupies, which we want to emphasise as being different things.

[4] As we discuss further below, aircraft make use of both the atmosphere (for fuel combustion and lift) and the V-space occupied by the atmosphere.

[5] While the notion of human competition with the atmosphere for use of V-space may seem fanciful, a simple example shows it not to be so. The volume of carbon dioxide gas emitted globally to the troposphere by human activities in 2025 was approximately *20 thousand cubic kilometres*, a massive quantity by any standard. Since the industrial revolution, total carbon dioxide emissions to the troposphere approach *1 million* cubic kilometres. Of course, the volume of the troposphere is much larger than this, so there is not, literally, too little V-space for both human emissions and the existing gases in the troposphere. However, the quantity of human carbon dioxide emissions has been large enough to have made an important difference in the concentration of carbon dioxide in the troposphere—increasing it by 50% since the beginning of the industrial revolution—the result of which is the climate crisis the world finds itself in.

from this perspective—considering the atmosphere itself as a tangible resource (akin to timber or soil resources) and the V-space it occupies purely as a source of space.

2.1.1 The layers of the atmosphere

10. Scientists consider the atmosphere itself (as opposed to the V-space it occupies) as comprising five physically distinct layers (Figure 1). The **troposphere** is the lowest layer, starting at the planet's surface and extending about 10 km above sea level into V-space. Nearly all weather occurs in this layer and the "blue sky" we observe from earth is due to scattering of sunlight in it. Air pressure drops, and temperatures get colder, as one climbs higher in the troposphere. The V-space occupied by the troposphere is where most air emissions from human activity are emitted[6] and where most of the emitted pollutants remain, becoming—effectively—part of the troposphere itself. Carbon dioxide—as a very long-lived gas—is an exception to this, eventually finding its way into higher layers of the atmosphere through material mixing. The troposphere is also where the oxygen necessary for human and animal respiration and for combustion is drawn from. Other gases are also extracted from it for use in human activities.

11. The troposphere is divided into two parts. The first, which occupies the V-space from the planet's surface to just a few hundred or thousands of metres is known as the atmospheric (or planetary) boundary layer (ABL).[7] This is the most active portion of the troposphere due to its close interaction with the surface. Above the ABL is the "free troposphere", which occupies the V-space from the ABL to the top of the troposphere. The air in free troposphere is, in relative terms, much calmer than that in the ABL (weather.gov, n.d.).

12. Next in V-space above the troposphere is the **stratosphere**, extending from 10 kms to about 50 km into V-space. The ozone layer, which protects the planet from much of the sun's high-energy ultraviolet (UV) light, is part of the stratosphere. Temperature actually rises with elevation in the stratosphere, which results in air that is less turbulent than in the troposphere. Many commercial passenger jets fly at cruising altitude in the lower part of the stratospheric V-space partly for this reason, but also because the jet stream flows near the border between the troposphere and the stratosphere. As a result, pollutant emissions from many aircraft flights occur in the stratospheric rather than the tropospheric V-space.

13. Above the stratosphere is the **mesosphere**, extending in V-space from about 50 km to about 85 km. Most meteors burn up in the mesosphere, making it the source of "shooting stars" that people enjoy watching. Other than transflight by spacecraft travelling to or returning from outer regions of the atmospheric V-space, no human activity takes place within the mesosphere (with the exception of "sounding rockets" occasionally and briefly launched into it for scientific research).

14. The thick layer of very thin air in the V-space above the mesosphere is called the **thermosphere**, which extends from about 85 km up to about 1000 km. High-energy X-rays and ultra short-wavelength UV radiation from the sun are mostly absorbed in the thermosphere, raising its temperature to hundreds or at times thousands of degrees.[8] So-called "low-Earth orbit" satellites orbit within the thermospheric V-space, as do the U.S. Space Shuttle, the International Space Station and the Hubble Telescope, among other spacecraft. The auroras that frequently light up night skies near the poles—known as the Northern Lights and Southern Lights—also occur in the thermosphere.

[6] Some emissions also occur in higher layers of atmospheric V-space from high-flying aircraft and spacecraft.
[7] Depending on the time of day and the season, the thickness of the V-space occupied by the atmospheric boundary layer changes. At night and in cool seasons, the layer tends to be thinner while during the day and in warm seasons, it tends to be thicker.
[8] However, the air is so thin that it would feel freezing cold to a human.

15. Although some scientists consider the thermosphere to be the uppermost layer of the atmosphere, others consider the **exosphere** its actual frontier. Here the air is so thin that it is not much different from outer space. Different definitions place the top of the exospheric V-space somewhere between 100,000 km and 190,000 km above the planet's surface (halfway to the Moon). Medium-earth orbit and geostationary-orbit satellites providing GPS navigation, weather forecasting, television and other services are found in the exospheric V-space.

2.2 Human benefits from use of the atmosphere and of V-space

16. From the scientific description of the atmosphere and atmospheric V-space above, it is clear that humans benefit from activity that occurs in all layers of the atmospheric V-space other than (arguably) the mesosphere, but even the latter is a source of benefits if we consider enjoyment of shooting stars. It is also clear that some benefits are directly related to the atmosphere (for example, the use of oxygen in the atmosphere for respiration and combustion) and others are related only to V-space (space for orbiting satellites, for example). Below we focus in more detail on these benefits, first discussing those associated with use of the atmosphere itself and then those associated only with V-space.

2.2.1 Benefits from use of the atmosphere itself

17. **Source of oxygen and other gases**—The atmosphere provides the oxygen-containing air that is essential for life for humans and many non-human species. The oxygen in air is also essential in supporting the combustion of fossil fuels and biomass used as energy in many human activities. In addition to oxygen, the atmosphere serves as a source of nitrogen gas and several so-called "noble" gases (argon, neon, krypton and zenon)[9], all of which serve important roles in the economy.

18. **Energy**—The atmosphere provides kinetic energy in the form moving air currents that are the basis of wind energy systems. The atmosphere is also increasingly used as direct source of heat energy collected via air-source heat pumps.

19. **Dispersal and elimination of air pollutants**—Humans emit massive quantities of various pollutants—gaseous, liquid and solid—into atmospheric V-space, using it effectively as a sink (see the following section for further discussion of the sink function of V-space). Once emitted into this V-space, these pollutants become part of materials that comprise the atmosphere (mostly the ABL and free-troposphere but also the stratosphere) and begin to be interact with the same material and energetic forces as interact with the atmosphere's naturally occurring constituents. Pollutants are thereby dispersed away from their point of origin by wind and energy currents, sometimes travelling great distances—as in the case of long-range transport of air pollutants from densely populated mid-latitudes to polar regions. Depending on the pollutant in question, it may be broken down by the sun's energy and/or chemical interactions with existing constituents of the atmosphere into other compounds that are sometimes, but not always, less harmful than the original material. An important case in which the secondary compounds are more harmful is the case of so-called "ground-level ozone", which is ozone formed—usually in urban airsheds—from the interaction of pre-cursor pollutants (nitrogen oxides and volatile organic compounds, or VOCs) in the presence of sunlight.[10]

[9] These gases are termed "noble" because they are almost entirely non-reactive with other materials. Another term for them is "inert" gases.

[10] Ozone is a highly reactive form of molecular oxygen that is damaging to any other material it comes into contact with, including human tissue, agricultural crops and building materials.

20. **Protection from solar radiation—**The atmosphere provides the planet and life on it with protection from damaging forms of electromagnetic waves emitted by the sun (for example, x-rays and high energy UV light). The best-known example of this protection is the so-called "ozone layer", which is, as noted, a part of the stratosphere. The ozone layer gained public notoriety in the 1980s because of concern that certain gaseous emissions from human activities were thinning it and reducing its effectiveness at absorbing short- and medium-wavelength UV light. Fewer people likely know that other layers of the atmosphere afford similar protection; for example, x-rays and ultra short-wavelength UV light, both of which would be very damaging if they were to reach the surface, are both partially absorbed in the thermosphere.

21. **Weather and climate regulation—**The atmosphere (mainly the troposphere) plays a crucial role in creating and regulating the planet's day-to-day weather and its long-term climate. Without the atmosphere, the planet would be an unliveable frozen mass. With it, we experience temperatures and weather that are suitable to life as we know it. Moreover, the temperatures and weather we experience have, since the last ice age, varied within predictable and limited extremes, providing the planet with water, warmth and other benefits in mostly favourable amounts. This relatively benign climate regime has played a crucial role in allowing modern societies, cultures and economies to evolve.

22. While the atmosphere is crucial to the weather and climate we enjoy, it is important to understand that it is not *synonymous* with them. The creation and regulation of weather/climate is the result of complex global, regional and local interactions between the sun's energy, the troposphere, the oceans and the land—interactions so complex they are not fully understood by science. They involve massive and continuous transfers of both material and energy among these global systems, of which the atmosphere is just one.

23. **Air travel and transport—**Aircraft carrying a wide range of people and materials make direct use of the atmosphere as the source of the oxygen required for combustion of fuel and as the source of wing lift that keeps them from falling out of the sky (a phenomenon known as the Bernoulli effect). Along with these benefits, the atmosphere presents disbenefits to air travel as well. The same air that provides essential lift when aircraft are climbing and descending becomes a significant source of drag when they reach cruising altitude (and require less lift). This is one reason why modern aircraft cruise just above the top of tropospheric V-space, where the air is thinner and creates less drag.

24. Humans have strong personal and collective connections with the atmosphere. The blue skies associated with a beautiful day; the enjoyment of cloud gazing or being witness to the power of a bolt of lightning; the spectacle of the northern and southern auroras; and the sense of wonder in seeing a shooting star are all atmospheric phenomena that touch humans deeply and have done for millennia.

2.2.2 Benefits from use of V-space

25. **Sink for air pollutants—**As noted above, humans emit massive quantities of various pollutants—gaseous, liquid and solid—into V-space; mainly into that part of V-space occupied by the troposphere, but also in stratospheric and higher V-space. The quantities of pollutants involved in this sink use of V-space can be staggering. As noted above (Footnote 5), human emissions of just one gaseous pollutant—carbon dioxide—amount to some 20 thousand cubic kilometres annually. Though small in comparison to the volume of V-space occupied by the troposphere into which they are emitted, this is by any measure a massive use of a pollution sink. Pollution emissions into V-

space are often responsible for reductions in the other benefits humans receive from both the atmosphere and V-space. Of arguably greatest concern today is the reduction in the benefits associated with climate regulation provided (partly) by the atmosphere due (mainly) to emissions of greenhouse gases into the troposphere. Also of major concern is the reduction in the benefits of breathable air in urban areas where massive use is made of the V-space sink for absorption of tailpipe and smokestack emissions of particulate matter and other pollutants.

26. **Energy** – Humans make use of solar energy that reaches the planet through V-space (despite the atmosphere blocking much of it) for a variety of purposes. Most importantly, this energy keeps the planet warm enough to be habitable and serves as the energy source for photosynthesis, the basis for most plant life. Increasingly, solar energy is captured by humans and converted directly to electricity via photovoltaic arrays. It has been similarly captured for its direct heat value for millennia to heat water and dry materials like salt and fish. Human use of the sun's energy is one of the instances in which we compete with the atmosphere for the benefits of V-space. The atmosphere disrupts the flows of useful energy from the sun to the surface in various ways that reduce our ability to benefit from it (for example, cloud cover that reduces production of electricity by photovoltaic panels).

27. **Air travel and transport –** Aircraft make considerable use of V-space (specifically, that part of it occupied by the troposphere and the lower stratosphere) when in flight.[11] A commercial aircraft requires a quantity of V-space equal to about 17 cubic kilometres[12] when aloft in order to operate safely, creating competition for space among airline companies and other operators of aircraft. As noted earlier, the atmosphere plays a direct role in air transport and travel as well, making this an activity that benefits from both the atmosphere and V-space.

28. **Space-based communications/weather predication/research –** Communications, weather prediction and research are facilitated by use of V-space in two ways. First, V-space is used by an ever-growing number of spacecraft of various sizes and types that orbit in the part of V-space occupied by the thermosphere and the exosphere.[13] These spacecraft include satellites owned by private companies and governments, as well as the International Space Station, the Hubble Telescope (and many other orbiting telescopes) and, on occasion, temporarily orbiting spacecraft like the U.S. Space Shuttle. These spacecraft can serve any of communication, weather prediction and research purposes depending on the craft in question.

29. Second, V-space is used for the propagation of the electromagnetic (radio) waves that spacecraft use to send and receive information to and from the earth. Though radio waves are commonly thought of as travelling "through the air" (they are even colloquially called "airwaves"), it must be emphasized that this is not the case. Radio waves do not require air or any other material to propagate.[14] Indeed, they propagate best in a vacuum, travelling almost indefinitely in outer space.

[11] As noted earlier, the atmosphere itself plays a direct role in air transport and travel as well through its provision of oxygen for combustion and lift for aircraft, making air transport an activity that requires both the atmosphere and the V-space it occupies.

[12] Safe operating standards call for a vertical separation of about 300 m between aircraft and a horizontal separation of about 7.5 km.

[13] There is so much competition among communications companies and governments for space in the low-earth orbits used by certain kinds of satellites that the World Economic Forum made the issue part of its 2022 global risks report.

[14] The same is not true of soundwaves, which propagate only in the presence of a gas or other material medium. The fact that soundwaves do, in fact, travel "through the air" may be why it is commonly believed that radio waves do the same.

The gases and other materials in the atmosphere impede propagation of radio waves in various ways and to varying degrees, almost always causing deterioration in the quality of the signal.[15]

30. **Land-based communications/weather predication/research** - Radio waves are also emitted from land-based infrastructure (for example, cellular telephone and radar towers) used for communications, weather predication and research. These radio waves mainly propagate through V-space close to the planet's surface, sometimes travelling just a short distance[16], though they may also travel to the V-space occupied by the outer layers of the atmosphere and beyond.

31. **Aesthetic and cultural value**: Though most of the aesthetic and cultural value associated with "looking up" is related to phenomena that are due to processes that occur in the atmosphere itself (e.g., blue skies and auroras), one of the most fundamental values—that of simple "star gazing"—is not. The light reflected from distant celestial bodies arrives at the earth by travelling through V-space. The atmosphere is, in fact, a hinderance to it, which is why the most powerful telescopes are found in the part of space occupied by the very upper reaches of the atmosphere where the air is extremely thin (and why no one goes star gazing on cloudy nights!).

2.3 Existing accounting guidance

32. Below we consider the guidance related to atmosphere and V-space in the SEEA-CF, the SEEA 2003, the SEEA-EA and the SNA 2025.

2.3.1 Existing guidance in the SEEA-CF

33. Regarding the atmosphere itself, the SEEA-CF is clear that it is not considered an environmental asset (para 5.16): "the volume of air in the atmosphere is also not in scope of environmental assets in the Central Framework". It clarifies the reasoning for this by noting (preface para 30) that the atmosphere's "stocks are too large to be meaningful for analytical purposes". Other than these references, the SEEA-CF makes no mention of the atmosphere in its discussion of environmental assets. There are, however, many mentions of other benefits of the atmosphere that could be relevant to its consideration as an environmental asset in the revised SEEA-CF. In particular:

- The atmosphere is mentioned in Chapter 3 on physical flow accounts as the source of "inputs from air" (an example of a "natural input") which are "substances taken in by the economy from the air for purposes of production and consumption" (para 3.63). Specifically, the following inputs from air are mentioned: oxygen used for combustion; carbon dioxide and nitrogen absorbed by cultivated biological resources during their growth; and "substances absorbed

[15] A famous example of the atmosphere improving rather than impeding radio wave propagation is the phenomenon known as "nighttime reflection". Nighttime reflection happens because certain ions that absorb radio waves are created in the upper mesosphere when the sun is shining. At night, these ions disappear and the radio waves propagate straight through the mesosphere to the lower thermosphere where a different kind of ion reflects them back to earth. They can then bounce off the earth and return to thermosphere to be reflected again. Such signal "skipping" allows AM radio signals to travel very long distances (hundreds or even thousands of kilometres) on clear nights. Anyone old enough to remember when AM stations dominated the commercial radio market will likely be familiar with this phenomenon from his/her childhood.

[16] Some radio waves used by so-called 5G cellular telephone networks, for example, can travel only short distances before being degraded by material obstacles in their way, including the gases in the atmosphere. Indeed, the fact that radio waves become increasingly less able to penetrate the atmosphere as their ability to data increases (that is, as their frequency increases) is one of the limiting factors in increasing the speed and data capacity of cellular networks. At high enough frequencies (around 300 GHz), the atmosphere is essentially opaque to radio waves. Fortunately, it becomes transparent to electromagnetic waves again at the much higher frequencies where visible light is found (400-790 THz), the so-called "optical window".

…[by]…other industrial processes." It is not clear what "absorbed" means here. It may or may not include the industrial extraction of gases from the atmosphere for use in the economy. As noted earlier, the noble gases argon, neon, krypton and xenon are all economically important gases extracted directly from the atmosphere. (Note that Guidance Note B1 on the description of physical supply and use tables in the SEEA-CF is also relevant to this issue.)

- The atmosphere is further recognized in Chapter 3 as the sink into which "emissions to air[17]" flow (para 3.91 and Section 3.6.3): "gaseous and particulate substances released to the atmosphere by establishments and households." The SEEA-CF measures the physical flows of these emissions but does not account for their accumulation in V-space. (Note that Guidance Note B3 on the treatment of carbon flows in the SEEA-CF is also relevant to this issue.)
- Further on in Chapter 3 (para 3.216), the atmosphere is noted to be related to water flows through transpiration and evaporation processes.
- Chapter 3 also recognises in its discussion of energy flow accounts (Section 3.4) that energy production is associated with the sun's energy (both photovoltaic and direct use of heat) and with wind energy, though it ties neither of these explicitly to the atmosphere. It is correct that solar energy should not be tied to the atmosphere, since (as noted in Section 2.2.2) solar radiation propagates through V-space without the need for the atmosphere as a medium. Wind energy, on the other hand, is directly related to the atmosphere, since it is moving air currents that turn the blades on wind turbines.
- In Chapter 4 (Environmental Activity Accounts and Related Flows), use of the atmosphere as a sink for air emissions is noted as one justification for compiling accounts related to environmental expenditures (para 4.126). Section 4.4.5 on permits to use environmental assets specifically addresses the issue of permits to use the environment as a pollutant sink (para 4.182): "this relates to the right to use the environment, i.e., the soil, water, air and associated environmental assets, as a sink for emissions from economic activity." The SEEA-CF concludes (para 4.183.c.ii) that in the case where the sink in question does not qualify as an asset (as for the atmosphere), payments for emission permits should be considered taxes on production rather than payments for resource licences. This is consistent with the treatment in the SNA (see below for further discussion).
- In Chapter 5 (Asset Accounts), there is little mention of the atmosphere beyond the already noted statement (para 5.16) that it falls outside the scope of environmental assets. Section 5.11 (Asset accounts for water resources) makes the basic point that the atmosphere is involved in global water flows because it is related to evaporation and transpiration processes and to precipitation. The text is clear, however, that the stock of water held in the atmosphere is excluded from the definition of water stocks in the SEEA-CF (para 5.476).
- Chapter 5 also excludes all renewable energy sources, including the sun, the wind and the air, from consideration as environmental assets. It notes (para 5.228) that "opportunities to earn resource rent based on sources like wind, solar and geothermal should be expected to be reflected in the price of land." We discuss this further under our review of the relevant material from the SNA 2025, in which renewable energy resources are (for the first time) recognized as economic assets.

[17] Note that it is a misnomer to call these "emissions to air". They are, in fact, emissions into V-space. Once in V-space, they then mix with the other gases, materials and energy present, becoming part of the "air" (more properly, part of the troposphere).

34. Regarding V-space, the SEEA-CF implicitly recognises this space as an environmental asset, though as part of its land asset category rather than as a stand-alone asset. The relevant text in para 2.121 states that a country's "economic territory" is the land area "under effective control of a single government…including islands, *airspace*, territorial waters and territorial enclaves" (emphasis added). Since land is an asset within the SEEA-CF asset boundary and "airspace" is, according to this definition of economic territory, part of land, then "airspace" (or V-space as we label it here) is also implicitly within the boundary. V-space that is above areas other than those within national boundaries (such as above the open oceans) is not considered an asset in the SEEA-CF because those areas are outside the control of single governments.

35. The SEEA-CF does not define "airspace" explicitly but, given the emphasis on government control in the definition of economic territory, it would be logical to assume that "airspace" extends to the height at which military aircraft fly, as this is the height to which countries attempt to exert on-going and complete control over their "airspace". Today, that height is something like 18,000 metres.

2.3.2 Existing guidance in the SEEA 2003

36. The SEEA 2003 (an interim version of the handbook that served as the starting point for developing the SEEA-CF), did recognize the atmosphere as an asset, but only in its ecosystem asset category. Unlike the SEEA-CF, the SEEA 2003 classification of environmental assets included a category for "Ecosystems" in addition to categories for "Natural Resources" and "Land and Surface Water" (see Table 7.2, p. 252). The latter two categories correspond closely to the SEEA-CF classification of environmental assets. Even if the atmosphere was considered an environmental asset in the SEEA 2003, para 7.80 made it clear that "there is no meaningful way of measuring [its] total stock levels." It went on to recommend the use of environmental indicators which express the change in terms of some other units; for example, "using an air quality index to measure changes in the quality of air".

37. Like the SEEA-CF, the SEEA 2003 implicitly recognized V-space as an asset because of its connection to the economic territory (or "national territory" as it called it) and the equivalence between its land asset and the national territory (para 3.80). The SEEA 2003 also included a discussion of competition for use of what it termed "environmental functions" and how this can lead to "environmental elements" becoming assets over time. It notes three ways in which such competition manifests itself, one of which is competition for space (para 7.33): "Spatial competition occurs when the amount of space available is inadequate to satisfy existing or expected future wants. For example, space for transport or agriculture may be at the expense of space for ecosystems." Though competition for V-space is not mentioned explicitly in this discussion, it would seem to be implicitly included since "transport" includes activities that occur in V-space.

2.3.3 Existing guidance in the SEEA-EA

38. Similarly to the SEEA 2003, the SEEA-EA considers the atmosphere as a sort of ecosystem. However, in the SEEA-EA, the atmosphere is seen as an extension of terrestrial ecosystems rather than as an ecosystem type unto itself.[18] The relevant text from its discussion of spatial units for ecosystem accounting is the following (emphasis added):

    - "3.13 Atmospheric boundary. Several important ecological processes are based on the interaction with the atmosphere, including respiration, nitrogen fixation, and those associated

[18] It is worth noting that ecologists have recently accepted that the atmosphere be recognized as an ecosystem type unto itself in the context of the new IUCN Global Ecosystem Typology, the reference classification of ecosystem types used in the SEEA EA.

with the impact of air pollution on vegetation and fauna such as air filtration. To establish a clear boundary for accounting, *the atmosphere directly above and within an ecosystem is considered part of the ecosystem asset* as one of the abiotic components within the spatial unit.

3.14 The interaction between the Earth's surface and its ecology, and the atmosphere is limited to the atmospheric boundary layer. For accounting purposes, this forms the natural upper boundary of ecosystem assets. The atmospheric boundary layer is defined as the bottom layer of the troposphere that is in contact with the surface of the earth (American Meteorological Society, 2020). Parts of the atmosphere above this layer are not considered ecosystem assets."

39. From this, it can be seen that the SEEA-EA recognizes the atmosphere directly above a given ecosystem to be part of that ecosystem, but only the relatively small portion of the atmosphere extending to the top of the atmospheric boundary layer (ABL).

40. Recall from the discussion in Section 2.1.1 that the ABL is the portion of the troposphere extending from a few hundred to a few thousand metres above the planet's surface. As the troposphere itself extends to as much as 10 km above the surface, most of it—along with all the atmospheric layers above it—is excluded from the SEEA-EA definition of ecosystems. It seems that the authors of the SEEA-EA were not fully satisfied with this, as the handbook goes on to note (para 3.15) that "further discussion on a more complete accounting treatment for the atmosphere is part of the SEEA EA research agenda including the consideration of the atmosphere as a separate environmental asset."

41. It is clear that the SEEA-EA's ecosystem definition does not extend to the inclusion of V-space. Thus, when it says that the atmosphere is part of ecosystems, it is referring, literally, to the gases, other materials and energy the constitute the atmosphere. This conclusion is supported by para 11.43: "the provision of space is not considered as an ecosystem service and consequently the value of ecosystem assets, particularly terrestrial ecosystems, excludes the value of the provision of space."

42. At the same time, the SEEA-EA notes that the "environment" provides two types of benefits in addition to ecosystem services, one of which is so-called "spatial functions".[19] Two main spatial functions are identified (para 6.36, third bullet): "(i) the use of the environment for transportation and movement on land, water or through the air or as the base for buildings and structures; and (ii) the use of the environment as a location in which pollutants and waste are deposited, i.e., use of the environment as a sink". These concepts are clearly related to the benefits mentioned in Section 2.2.2 regarding the use of V-space for air transport and as a sink for pollutants.

43. Further on (para 11.42), SEEA-EA attributes the provision of space specifically to land, aligning it with the treatment in the SEEA-CF: "A key function of land is to provide space. Land, and the space it represents, define the locations within which economic and other activity is undertaken and within which assets are situated. This role of land is a fundamental input to economic activity and has significant value in many locations." Though this description of land does not mention V-space explicitly, it could be seen implicitly to include it, since there are many examples of "economic and other activity" for which V-space provides the "location".

44. The final relevant SEEA-EA discussion is found in its chapter on specific applications of ecosystem accounting (Section 13.4.3 and Annex 13.2). There a detailed discussion is found of accounting for planetary stocks of carbon, including the carbon held in the gases of the atmosphere (mainly carbon dioxide and methane). Whether such an account is intended for compilation by countries or simply at the global level is not clear, but it would seem that compiling a carbon stock account for the national

[19] The other benefit is so-called "abiotic flows".

atmosphere as defined by the SEEA-EA (that is, the portion of the atmosphere found in the ABL directly above the national boundaries) would be of limited analytical value.[20] Since atmospheric carbon is well mixed, the carbon in a unit of the atmosphere above one country is essentially the same as it is above all other countries. Moreover, no country has any meaningful control over the quantity of carbon in its atmosphere, since it results from processes (including human emissions of greenhouse gases) that are mostly out of the control of individual countries. That said, it may be of interest to countries to compile other components of a carbon stock account (say, an account for the stock of biospheric carbon or for the carbon bound up in the economy) at the national level, since these stocks are, at least partly, under the country's control. Since there appears to be no utility in a national atmospheric carbon stock account, we say nothing further about it in this note. The matter is taken up in detail in Guidance Note D1 on the possibility of including carbon accounts in the revised SEEA-CF.

2.4 Existing guidance in the SNA

45. Like the SEEA-CF, the SNA 2025 is unequivocal that the atmosphere falls outside its asset boundary, though the reason given is different. Whereas the SEEA-CF excludes the atmosphere because it is too large to be meaningfully measured, the SNA 2025 excludes it because ownership rights to it cannot be exercised (para 1.68): "Resources such as the atmosphere or high seas, over which no ownership rights can be exercised…are *not included* [in the asset boundary]…" (emphasis added). Similarly, in its chapter on measuring the sustainability of well-being (Chapter 35; para 35.33), the SNA 2025 states: "From the perspective of the integrated framework of national accounts, including the balance sheets, *the scope of natural capital excludes* environmental assets over which ownership rights have not, or cannot, be established, such as open seas or *the atmosphere*" (emphasis added).

46. Despite these unambiguous statements, the SNA 2025 contradicts itself elsewhere by suggesting that *some* parts of the atmosphere might, in fact, be included within its scope of natural resource assets. This suggestion first occurs in Chapter 11 on capital accounts, but is repeated in several places[21]. Para 11.11c states: "Natural resources (AN3) are assets that naturally occur, such as land, mineral and energy resources, water resources, and animal, tree, crop and plant resources, that have an economic value and over which ownership may be enforced and transferred. Environmental assets over which ownership rights have not, or cannot, be enforced, such as high seas beyond national jurisdiction and *most parts of the atmosphere*, are excluded" (emphasis added). Just which parts of the atmosphere are excluded and which are considered to fall within the SNA 2025's boundary is, unfortunately, not addressed anywhere in the text.

47. It appears that the SNA 2025 has not yet settled how it views the atmosphere. In some places it is unequivocal that the atmosphere is not an asset. Elsewhere, it implies (without clarification) that some parts of the atmosphere are, in fact, assets. It also occasionally uses terminology referring to the atmosphere that suggests it could be considered a "resource" (para 1.68) or an "environmental asset" (para 35.33). Elsewhere (para 35.129), it notes that: "…it would be possible, conceptually, to compile accounts for the natural capital of the Pacific Ocean. A similar logic could be applied to *develop accounts for the atmosphere* on a more holistic basis" (emphasis added).

[20] It is worth noting that even a global carbon stock account might not be of meaningful analytical value given the uncertainty in the estimated stocks. For example, the current estimate of the stock of ocean carbon is 38–40 thousand Gt. The *uncertainty* in this estimate (2000 Gt) is twice the size of the estimated *total* stock of carbon in the atmosphere (870-900 Gt).

[21] This suggestion is also found in paras 11.22, 11.179 and 35.24, as well as in the Glossary of Terms under the heading for "Natural Resources".

48. The seemingly unsettled view of the SNA 2025 with respect to the atmosphere is reflected in the entry in its forward research (Annex 5; para A5.54) calling for further research: "It is considered important to further investigate possible ways of recording the atmosphere and measuring the value of depleting the atmosphere by using it as a sink. This research may have implications for the recording of emissions and other sinks."

49. Regarding V-space, the SNA 2025 (para 5.14) takes the same position as the SEEA-CF; that is, that "airspace" is part of the land asset associated with a country's economic territory. Again, the SNA does not clarify how "airspace" is to be measured but since its definition of economic territory is the source for the definition in the SEEA-CF, we again conclude that a reasonable interpretation of "airspace" would be that it extends directly above the national economic territory to the height at which the country maintains on-going and complete control of overflying aircraft—as noted above, this is currently about 18,000 metres.

50. In addition to the SNA 2025 material relevant to the atmosphere and V-space, three other aspects of the text are relevant to this Guidance Note. First, there is the discussion of the radio wave spectrum used for cellular telephone communications. Second, there is the discussion of payments relevant to pollutant emissions. Third, there is the recognition, for the first time ever in the SNA, of renewable energy resources as natural resource assets. These are treated in order below.

2.4.1 Radio wave spectra in the SNA

51. Beginning with SNA 2008 and continuing unchanged into the SNA 2025, the specific frequencies within the radio wave spectrum used for cellular telephone communications ("the spectrum" hereafter) have been collectively considered a natural resource. The classification of the spectrum as a natural resource asset was prompted by the need to account for the large sums of money some governments began raising in the 1990s by auctioning the use of specific frequency bands within the spectrum by cellular telephone communications companies.

52. The SNA's rationale for assigning the spectrum to the natural resource category—rather than, for example, simply creating a new category of non-produced, non-financial asset—is not clear. Since it is germane to the present discussion, it is worth considering whether, in fact, the spectrum has the characteristics of a natural resource asset and, if so, whether that might provide a justification for considering the atmosphere itself as an environmental asset in the revised SEEA. We explore this largely in Annex I, as it is only peripherally related to the primary issues that motivate this Guidance Note (see para 2). We note the principal conclusion of relevance from the discussion in Annex I in the following paragraph.

53. The principal conclusion relevant to this Guidance Note from consideration of the spectrum as a natural resource asset in Annex I is that the spectrum has *nothing* to do with the atmosphere itself. As noted in Section 2.2.2, radio waves do not require air or any other material to propagate. On the contrary, they propagate best in a vacuum and are actually hindered in their propagation by the materials that constitute the atmosphere. Thus, when the SNA 2025 considers the spectrum as a natural resource asset, it is not because the atmosphere itself plays any role in radio communications. Basic physics means that it cannot be so; the atmosphere is, in fact, a liability rather than an asset when it comes to radio communications. In fact, although the SNA 2025 fails to make this explicit, it is the V-space occupied by the atmosphere that is relevant in the case of the spectrum, as it is through V-space that radio waves propagate. This suggests that there may be a case for assigning some or all of the value of the radio spectra asset to V-space. Whether some of the value should also be assigned to the radio spectrum as an asset itself is taken up further—though not resolved—in Annex I. In addition, we provide further

discussion of the issue in Section 3.3 and, even though it is not one of the primary motivations of this Guidance Note, we provide accounting options in Section 4.3 since the development of it has revealed material and concepts that are of relevance to the issue.

2.4.2 Permits to emit pollutants

54. We turn now to the SNA 2025's discussion of permits for the right to use the environment as a sink for pollutants. Though such permits are issued for a variety of pollutants and under a variety of systems, the SNA 2025 focuses on cap-and-trade systems associated with greenhouse gases. As it notes (para 27.77), cap-and-trade systems are flexible market mechanisms that establish a maximum level of pollution—the "cap" in "cap-and-trade". Companies must have permits to cover each unit of pollution they emit. Permits are issued initially by governments. The permits may be issued at no charge or they may be auctioned to the highest bidder. Each permit stipulates a given amount of emissions that can be emitted in a given period (the quota). Companies that find themselves without enough permits to cover their emissions can purchase them from other companies that have excess—the "trade" in "cap-and-trade". Alternatively, they can reduce their emissions to fit within their permitted amounts by curtailing production or changing their processes to reduce emissions. Permits must be "surrendered" (returned to the government) when companies emit the pollutants covered by them. Cap-and-trade systems are seen by economists to be an economically efficient means of reducing emissions to agreed-upon levels.

55. The SNA 2025 recommends (para 27.80) recording emission permit systems as financial assets/liabilities valued at the auction price (zero if the permits are given away free of charge). Thus, the issuance of permits is regarded as the purchase of a financial asset – accounts receivable/payable – where the payment grants the acquirer the right to emit a pre-specified quantity of emissions sometime in the future. When a company surrenders the permit, it is recorded as a tax on production. The same treatment is, as noted earlier, applied in the SEEA-CF. Both the SEEA-CF and the SNA 2025 (para 27.86) recognize that this treatment of emissions permits would require reconsideration if the atmosphere itself were treated as an asset. We come back to this point the discussion of conceptual and measurement issues in Section 3.

2.4.3 Renewable energy assets

56. The SNA 2025 extends the boundary of mineral and energy resources to include renewable energy resources, which it defines (para 11.200) as comprising "the cumulative quantities of kinetic, radiative and thermal energy recoverable from moving water (hydro and ocean energy), moving air (wind energy), hot underground and surface rock and water (geothermal resources) and incident solar radiation (solar resources)." The SNA 2025 also includes a category for "other renewable energy resources", recognizing that other sources (for example, ocean tidal energy) could become economically important in the future.

57. The SEEA-CF, as noted above, excludes renewable energy resources as distinct environmental assets on the grounds that any rent associated with them should already be captured in land rents. The SNA 2025 (para 13.19) rejected the SEEA-CF's position on the grounds that there are instances where: 1) the value of the land associated with renewable energy generation is zero (for example, solar panel arrays on public land); 2) land markets do not always capture the value of the renewable energy resource (for example, wind turbines on farmland where the rights to wind production are not associated with title to the land); and 3) land is not involved in the generation (for example, off-shore wind farms). The SNA 2025 recommends that renewable energy resources be valued in these instances using the same method as for other natural resources; that is, as the present value of the expected future resource rents.

58. As discussed earlier (sections 2.2.1 and 2.2.2), renewable energy can be related to both the atmosphere itself (wind energy, heat energy extracted from the air) and to V-space (solar radiation passing through this space to fall on photovoltaic cells or hot water heating systems, for example). Other forms of renewable energy (hydroelectricity and geothermal) have nothing to do with the atmosphere at all. We return to this point the discussion of conceptual and measurement issues in Section 3, which follows immediately below.

3 Conceptual and measurement issues

59. In this section, we draw upon the material presented in Section 2 to discuss the merit in the suggestion that the atmosphere be recognized as an environmental asset in the revised SEEA-CF. To start, it is necessary to review the SEEA-CF's current definition of environmental assets. They key passage is found in paras 2.16–2.19, which we repeat verbatim below (with emphasis added):

- "2.16 The use of natural inputs by the economy is linked to changes in the stock of environmental assets that generate those inputs. Asset accounts for environmental assets in *both physical and monetary terms* are an important feature of the SEEA.

  2.17 Environmental assets are the naturally occurring living and non-living components of the Earth, together constituting the biophysical environment, which may provide benefits to humanity. Although they are naturally occurring, many environmental assets are transformed to varying degrees by economic activities. In the SEEA, environmental assets are considered from two perspectives. *In the Central Framework, the focus is on individual components of the environment that provide materials and space to all economic activities.* Examples include mineral and energy resources, timber resources, water resources and land.

  2.18 *This focus reflects the material benefits from the direct use of environmental assets as natural inputs for the economy by enterprises and households.* However, this focus does not consider the non-material benefits from the indirect use of environmental assets (e.g., benefits from ecosystem services such as water purification, storage of carbon and flood mitigation).

  2.19 The coverage of individual assets does not extend to the individual elements that are embodied in the various natural and biological resources referred to above. For example, the various soil nutrients are not explicitly considered individual assets."

60. From the above passage and the material presented in sections 2.2.1 and 2.2.2 on the benefits of the atmosphere and V-space, it would seem that both the atmosphere and V-space meet the basic requirement for treatment as environmental assets in the SEEA-CF; that is, both are "components of the environment that provide materials and space to all economic activities" (see the emphasised text in para 2.17 above). Regarding the provision of materials, the most important of these are the oxygen provided by the atmosphere for combustion, along with the carbon dioxide, nitrogen and water required for terrestrial and aquatic life. Additionally, the atmosphere is the source of several increasingly important noble gases: argon, neon, krypton and zenon. Regarding the provision of space, the V-space occupied by the atmosphere is used massively as a sink for pollutants from economic and household activities. It also serves as the space through which radio waves used for many different types of communications propagate and as the space through aircraft and spacecraft fly.

61. SEEA-CF para 2.16 notes that asset accounts in both physical and monetary terms are a key feature of the SEEA system. While there is no explicit requirement that the environmental assets recognized in the SEEA-CF be measurable in both terms, all assets currently with its asset boundary lend themselves to this. The

fact that current accounting guidance for two assets—soil resources and water resources—is presented exclusively in physical terms simply reflects the lack of practical methods and data sources for their valuation. It is not a reflection of any conceptual obstacle. From this it is reasonable to conclude—even if the SEEA-CF does not say so explicitly—that its intention is that components of the environment recognized as environmental assets should lend themselves—in concept at least—to measurement in both physical and monetary terms. We next consider the possibilities for both kinds of measurement with regard to the atmosphere and V-space.

3.1 Measuring the atmosphere in physical terms

62. Recalling that the SEEA-CF is a framework intended for application at the national level (para 2.121), the question here is whether there is a meaningful physical measure of the atmosphere as a stock that could be applied at the national level (that is, for the national economic territory as defined in para 2.121).

63. The first point is to recall that the atmosphere, as noted earlier, is not to be understood as a static stock but as a dynamic system, constantly in flux in terms of its energy content, its physical extent above the planet's surface and its composition. This dynamic nature immediately casts doubt upon the application of standard stock accounting concepts of opening and closing stocks reconciled by intra-period changes to the atmosphere—the system simply does not lend itself to this kind of description in the way that, say, timber stocks or oil reserves do.

64. The above concern aside, the question remains as to just what would be the object of measurement if a stock account were to be compiled. Most obviously, we might measure the mass of all gaseous components of the atmosphere. This, however, does not change in any meaningful way from one period to the next—even accounting for human emissions of greenhouse gases—so its measurement would be meaningless (Trenberth and Smith, 2005).

65. Next, we might consider measuring the individual components of the atmosphere that provide material benefits to the economy. These are, as noted, oxygen, water, carbon dioxide, nitrogen, and the noble gases. In the cases of oxygen, nitrogen, and the noble gases, again, there is no meaningful change in the quantities of these from period-to-period, so, again, their measurement is of no interest.

66. In the case of carbon dioxide, there is—of course—a meaningful increase in the amount found in the atmosphere from year-to-year due to human emissions. It is questionable, however, that this increase should be considered the increase in the size of an asset, since it is the primary cause of climate change. It would be more sensible to think of this increase as a deterioration in the condition of the atmosphere as a component of ecosystems, which means it should be measured in the ecosystem condition accounts of the SEEA-EA and not in the SEEA-CF. Indeed, as noted in Section 2.3.3, the SEEA-EA already includes guidance for the development of a detailed carbon stock account that includes measures of the stock of carbon in the atmosphere.

67. The same point can be made regarding water in the atmosphere. Its quantity is increasing due to climate change, but this increase would be wrongly said to an increase in an asset. It too would be most sensibly accounted for as the change in the condition of the atmospheric ecosystem in the SEEA-EA.

68. There is another perspective from which the atmosphere might be measured in physical terms; that is, as a source of renewable wind energy and heat. However, as it stands, the provision of benefits in *energy* terms is not included in the SEEA-CF as a basis for recognising environmental assets. Only benefits in terms of "materials and space" are recognized (para 2.17). Thus, recognition of the atmosphere's energy content as an asset would require expansion of the relevant benefits recognized in the SEEA-CF from just materials and space to energy as well. Such an expansion will, in fact, be unavoidable if the revised SEEA-

CF chooses to follow the SNA 2025 by adding renewable energy resources to its asset boundary. The matter of the revised SEEA-CF's coherence with the new SNA is the subject of a different Guidance Note (A9), so the issue of the inclusion of renewable energy assets is not discussed further here, other than to note that acceptance of renewable energy into the asset boundary would mean there would be no need to account for atmospheric energy as a separate asset.

69. From the above, it seems there is no basis or need for physical accounting of the atmosphere as an environmental asset in the SEEA-CF. Such accounts would either be:

- meaningless due to the unchanging amounts (air itself and its components oxygen, nitrogen, noble gases)
- inappropriately categorized as assets and properly accounted for as changes in atmospheric ecosystem condition (water vapour and carbon dioxide), or
- already covered by other assets that are likely to be included in the revised SEEA-CF (renewable wind energy and heat).[22]

3.2 Measuring the atmosphere in monetary terms

70. Given the conclusion that physical accounting for the atmosphere is not possible, appropriate or necessary in the revised SEEA-CF, we turn to the question of whether it is conceivable to account for it in monetary terms. Before doing so, it is worth recalling the point made earlier that all assets currently within the SEEA-CF boundary are measurable in physical terms and most are also measurable in monetary terms. The atmosphere, if it were to be accepted into the asset boundary and measured only in monetary terms, would be a significant exception to this.

71. To start with, it should be noted that it is nonsensical to consider the monetary value of air itself. Air is, for all intents and purposes, infinitely abundant and freely available to all who wish to use it. It, therefore, has no monetary value. This leaves us with the question of whether other material benefits of the atmosphere might have measurable values. Note that we consider the possible value of the V-space occupies by the atmosphere separately in the following sub-section.

72. In terms of material benefits, we can again mention the provision of oxygen, nitrogen, water, carbon dioxide and the noble gases. Each of these has, in principle, an economic value, since they are all inputs into economic activities that result in the production of marketed goods and services. Oxygen is essential to combustion processes that are nearly ubiquitous in the economy, given the wide reliance on fossil fuels as energy sources. Nitrogen is an essential input into production for certain crops, including alfalfa and soybeans. Water is, of course, essential to production of all crops, not to mention its role in other industrial processes. Carbon dioxide is also essential to all crop production. The noble gases are much less widely used, though they have high value in specific applications; for example, in lighting and electronics manufacturing.

73. As well-mixed gases in the atmosphere that are available in essentially limitless quantities, oxygen, nitrogen, carbon dioxide and the noble gases—like air itself—have no monetary value. Water, on the other hand, is not evenly distributed and does have value due to its relative scarcity in certain places. This scarcity partly explains the rent that arises on land of different types; farmland rents, for example, are due in part to the availability of precipitation to support crop growth.

[22] Here we are supposing that the revised SEEA-CF will, in fact, align itself with the SNA 2025 and recognize renewable energy resources as environmental assets.

74. In principle, the rent associated with agricultural land could be split into its component parts; for example, rent due to water in the atmosphere (that is, precipitation); rent due to soil quality; rent due to proximity to markets and so-on. While doing so may be an interesting academic exercise, there is little justification for it as part of a set of environmental accounts. For one thing, agricultural land is already recognized as an environmental asset in the SEEA-CF and in the SNA, so its value (including the implicit value of water in the atmosphere) is already captured by national balance sheets. For another, the splitting of land rents between the various components of the environment that give rise to them is essentially an ecosystem modelling exercise that is best carried out in the context of the SEEA-EA. Finally, separating land rents into all their components in the SEEA-CF would not be possible without recognizing ecosystems as assets, since some rents—such as the value of wild pollination—are associated with pure ecosystem services.

75. From the discussion above, we find no basis for recommending that either physical or monetary stock accounts for the atmosphere itself be included in the revised SEEA-CF. We turn next to the possibility of doing so for V-space.

3.3 Measuring V-space in physical and monetary terms

76. As discussed throughout this Guidance Note, the V-space occupied by the atmosphere is distinct from the atmosphere itself and should, therefore, be considered separately from the perspective of expanding the environmental asset boundary in the revised SEEA-CF. In considering this, the first point to note is, as discussed in Section 2.3.1, that the SEEA-CF *already recognises* V-space as an environmental asset, though implicitly as part of land rather than as a distinct asset. As further discussed in Section 2.3.1, though neither the SEEA-CF nor the SNA defines the "airspace" of a country explicitly, the implicit definition would be that it extends to the height at which military aircraft fly (currently about 18000 metres). This would imply that the SEEA-EA's limitation of the atmosphere as an ecosystem asset to just that part found in the ABL would not be applied in the SEEA-CF. Rather, in the revised SEEA-CF, a country's airspace should be defined as the area directly above its economic territory extending to the height at which it controls overflying aircraft.

77. As for the measurement of the volume of this space in physical terms, such measurement (though readily done) would be—as in the case of measuring the air in the atmosphere—meaningless, as the volume does not change in any meaningful way from one period to the next.[23] It is sufficient to measure the physical area of the economic territory (which the SEEA-CF already accounts for in its land accounts) and note that the airspace is that volume of air extending above this territory to a height of 18000 metres (or whatever the case might be).

78. Turning to the measurement of the monetary value of V-space, the possibilities here seem meaningful, since there are rents that arise from competition for use of the space. One form of competition—that for use of V-space to transmit radio waves of specific frequencies for the purposes of cellular telephone networks—is already recognized as giving rise to a valuable asset in the SNA 2025, where it is labeled the radio spectrum (see the earlier discussion in Section 2.4.1). The spectrum is not considered an asset in the SEEA-CF and is given only brief mention by it in a footnote on page 138. It appears from that footnote that the spectrum is excluded from the SEEA-CF asset boundary because it is not "biophysical" in nature. This is certainly true—as noted earlier, the spectrum is essentially an abstract concept. However, the human-produced radio waves that propagate through V-space, including—but not limited to—those used by cellular telephone networks are anything but abstract. They are very much real and they make use of V-

[23] The volume would only change if there were a change in the maximum height at which overflying aircraft were controlled. This height is unlikely to change much in the future, since above approximately 13,000 metres, the air in the stratosphere is too thin to provide the uplift needed to keep planes other than specialized military aircraft aloft.

space to propagate, the very same space that the SEEA-CF already implicitly recognizes already as an asset (though one tied to land). This leads us back to a point made earlier in our discussion of the spectrum (Section 2.4.1): the treatment of the spectrum as an asset in the SNA provides support for the notion that V-space should be seen as an asset unto itself.

79. From the above, it would seem that the SEEA-CF's exclusion of the spectrum from its asset boundary is indefensible, based both on its economic importance and also on its relationship to the land asset, which implicitly includes the V-space used by radio waves for propagation.

80. Another source of competition for V-space is its use by humans as a sink for pollutants. As discussed above (Section 2.2.2), human use of V-space as a sink for carbon dioxide alone is so significant as to have increased atmospheric concentrations of carbon dioxide levels to 50% above their pre-industrial levels, causing major disruptions in the global climate system. Another example of competition with the atmosphere for V-space is urban smog (where too many pollutants are discharged into local airsheds for them to effectively disperse, leading to temporary build-ups in pollutants with negative impacts on human health and economic activity). Yet another is the build-up of chemicals in the upper atmosphere that degrade the so-called ozone layer and reduce its effectiveness at protecting the earth from the sun's damaging rays. These are all examples of human activities competing with the atmosphere for use of V-space. It should be noted that there is no meaningful competition between economic agents for use of the space, since it has, for all intents and purposes, an infinite capacity to accept pollutants. No economic agent is physically prevented from using the space as a sink by this use by another economic agent.

81. Human competition with the atmosphere for use of V-space gives rise to a form of scarcity that did not exist in earlier times when the scale of human activities was small relative to the planet. It is not scarcity in the economic sense, however, since ecosystems do not enjoy property rights. Governments can, however, in their roles as legal owners and stewards of the V-space above their national territories act to create economic scarcity by legal means. This is one interpretation of what they do when they oblige economic agents to acquire permits for the right to emit pollutants into the space. The value of such permits (assuming they are not given away freely but auctioned instead) could serve as a basis for valuing the space as an environmental asset. This would be similar to the use of the value of the auctioned rights to use V-space for the purpose of propagating radio waves for cellular telephone networks as the basis for valuation of the spectrum in the SNA.

82. While one interpretation of payments for permits to emit pollutants is governments attempting to create a market to efficiently allocate the services of a scarce resource, this is not the only interpretation. Such payments can also be seen as Pigouvian taxes intended simply to internalize the external costs of excess use of V-space as a pollutant sink. Just how permits to use V-space as a sink for pollutants should be interpreted is an interesting matter, but not one that must be resolved here. For the primary purposes of this Guidance Note, it suffices to note that such permits offer a basis for valuation of V-space as an asset. Nevertheless, since the development of this Guidance Note has revealed material and concepts that are of relevance to the issue, we offer accounting options related to emission permits in Section 4.4

83. This raises another matter, touched on briefly already, which is whether payments by cellular telephone companies for the right to transmit radio waves at certain frequencies in certain parts of V-space should be properly understood to be values of V-space rather than of the radio wave spectrum itself. The current treatment in the SNA 2025 assigns all such value to the spectrum asset; the discussion here suggests that some (or maybe all) of it should be attributed to the V-space asset, since the scarcity that gives rise to the asset is as much (possibly more? entirely?) due to the scarcity of V-space as it is due to the scarcity of frequencies in the radio wave spectrum. One point that argues in favour of considering V-space to be the truly scare factor is that V-space is strictly limited (there being no means of creating more space above,

say, a city for radio waves to propagate), whereas the spectrum is "enlargeable" and "reusable" within certain constraints. Such enlargement and reuse of the spectrum is regularly witnessed in the evolution of cellular networks; for example, 5G networks making use of frequencies that had no part in 3G networks and also repurposing frequencies used in 3G network to serve 5G network requirements) We pursue this issue further in Annex I and in the presentation and discussion of accounting options in Section 4.

84. A third way in which competition for V-space manifests itself is in the form of air travel and transport. As noted earlier (Section 2.2.2), safe navigation for commercial airliners requires a volume of V-space equivalent to about 17 cubic kilometres. Thus, competition for V-space above cities with major airports (and, indeed, anywhere where aircraft—including drones—of any sort fly) is meaningful. Countries are responsible for ensuring the safe passage of aircraft through their V-space, doing so by mandating and funding installation of sophisticated equipment to track aircraft, communicate with them, ensuring their safe take-off and landing and provide emergency services in the event of an accident. These functions are sometimes provided by government agencies or publicly-owned companies and, less frequently, by private companies. Fees are charged to the operators of aircraft flying within or over national territories to cover the costs of providing aircraft control services. In principle, these fees could be seen as payments of rent on use of the V-space, though is not clear that the fees charged are designed to capture this rent or simply to cover the costs of providing the services. We consider this question further in Annex II, though we do not try to resolve it. It is sufficient here to note that such fees may offer another basis on which to value V-space as an asset.

85. From the above, we find, as with the atmosphere, no basis for a physical measure of V-space (noting that it is simply "equal" to the area of the economic territory multiplied by whatever is the maximum height at which aircraft are controlled over the territory). Unlike for the atmosphere, however, we find that there is a basis for monetary measurement of the V-space above a national territory due to its economic scarcity including for the propagation of radio waves and for the emission of pollutants.

4 Proposed accounting options

86. Based on the discussion in sections 2 and 3, we present below the options as we see them for responding to the need "to articulate how the atmosphere and its functions may be appropriately characterised in accounting terms", as the mandate of this Guidance Note was given by the UNCEEA's Technical Committee on the SEEA Central Framework. We present options for the following four issues:

- **Issue 1**—Inclusion of the atmosphere in the revised SEEA-CF asset boundary
- **Issue 2**—Inclusion of V-space in the revised SEEA-CF asset boundary
- **Issue 3**—Inclusion of radio spectra in the the revised SEEA-CF asset boundary
- **Issue 4**—Treatment of permits to emit pollutants in the revised SEEA-CF

4.1 Issue 1—inclusion of the atmosphere in the revised SEEA-CF asset boundary

87. Regarding Issue 1, based on the discussion in sections 2 and 3, we find no basis for expanding the SEEA-CF asset boundary to include the atmosphere itself, despite its provision of material (and energy) benefits to the economy. We find this because:

- There is no meaningful basis for measuring the entire atmosphere or any of its of its beneficial material components in physical or monetary terms; they are effectively unchanging in physical terms and freely available to all who wish to use them and, so, are free.
- Though there is a basis for physical measurement of two of the specific material components of the atmosphere (the excess carbon dioxide and excess water vapour it holds due to human activities), these components do not provide benefits to the economy (rather, they are liabilities) and are best seen as degradation of the atmospheric ecosystems that are already measured in the SEEA-EA.
- The energy benefits of the atmosphere (wind energy and heat)—which are amenable to both physical and monetary measurement—do not justify addition of the atmosphere to the SEEA-CF asset boundary since they are equivalent to the renewable wind and heat energy assets we assume will be added to the SEEA-CF in parallel to their addition as newly recognized assets in the SNA 2025.

88. Based on the above, we propose no accounting options for Issue 1. Note that this does not preclude the possibility that the atmosphere might be considered an ecosystem asset in the context of the SEEA-EA in the future. If it were, a number of the non-market benefits it provides, such as "blue skies" and beautiful sunsets (see Section 2.2.1), might be attributed to it as ecosystem services. We do not explore that possibility here.

4.2 Issue 2—Inclusion of V-space in the revised SEEA-CF asset boundary

89. Though we conclude that the atmosphere cannot (or need not) be recognized as an asset, we find a case for recognition of the space occupied by the atmosphere above a country's economic territory—what we refer to as its V-space—as an asset in the revised SEEA-CF.[24] In coming to this conclusion, we recall that V-space is *already* implicitly recognized as an environmental asset in the SEEA-CF, though it is treated as part of land. We are, thus, not suggesting a broadening of the SEEA-CF asset boundary to include a new asset. Rather, we are suggesting options for reconsidering the treatment V-space as an asset to better reflect its importance to the economy. Our reasoning for considering new options is that V-space provides economic benefits that are distinct from those provided by land (or H-space) and these benefits are important enough to warrant their own asset category. One distinction between H-space and V-space is that the latter is scarce mainly when governments choose to impose their ownership rights on potential users through the requirement for permits and licences of various sorts. V-space is not scarce in the literal, physical sense in which H-space is (other than in the case of aircraft in flight). The same two economic agents quite simply cannot occupy the same piece of H-space for basic physical reasons (for example, two farmers cannot farm the same hectare of farmland). The same kind of physical constraint does not exist for V-space; no agent's use of V-space *physically* prohibits another's use, with, again, the exception of aircraft in flight. A related distinction is that human competition for V-space is more often with ecosystems than it is with other humans. Again, no automobile driver is prevented from emitting tailpipe exhaust into an urban airshed due to the fact that millions of others may be doing the same thing. However, those emissions collectively represent a major source of competition for the V-space above the urban area with the atmosphere (and atmospheric processes) that would otherwise exist there. The result of this competition, is, of course, the degraded air quality that is all too common in cities today.

[24] Note that V-space outside of the boundaries of national economic territories—for example, that over the open oceans—should not be considered an asset in the revised SEEA-CF even if V-space above economic territories is. This is due to the lack of any single government being able to exert legal control over the space.

90. Based on the above, we offer the following three options for consideration, summarized below and presented in Table 1 for greater clarity (with proposed changes shown in green):

- **Option 2a**—Make no change to the SEEA-CF environmental asset classification, leaving V-space as an implicit component of land and the associated freshwater and marine areas.
- **Option 2b**—Add a new asset called "Space above land" to the SEEA-CF classification, following land.
- **Option 2c**—Add a new asset call "Space" to the SEEA-CF classification, with two sub-categories beneath it, one for "Space on land" and the other for "Space above land".

Table 3 - Options for classification of V-space in revised SEEA-CF[25]

Option 2a (existing)	Option 2b	Option 2c
1.Mineral and energy resources	1.Mineral and energy resources	1.Mineral and energy resources
2. Land	2. Land	*2. Space*
3. Soil resources	*3. Space above land*	*2.1 Space on land*
4. Timber resources	4. Soil resources	*2.2 Space above land*
5. Aquatic resources	5. Timber resources	3. Soil resources
6. Other biological resources	6. Aquatic resources	4. Timber resources
7. Water resources	7. Other biological resources	5. Aquatic resources
	8. Water resources	6. Other biological resources
		7. Water resources

4.3 Issue 3—Inclusion of radio spectra in the revised SEEA-CF asset boundary

91. As noted above (see Section 2.4.1), the SNA 2025 treats the "radio spectra" as a natural resource asset, following its treatment in the 2008 edition of the handbook, where it was first added to the asset boundary. Since the spectrum is economically valuable and reflects—at least in part—use of the V-space asset that is already implicitly recognized in the SEEA-CF, the view here is that its exclusion from the SEEA-CF asset boundary is unjustified. This leads to the following three accounting options, summarized below and presented in Table 2 (with proposed changes shown in green):

- **Option 3a**—Include "Radio spectra" in the environmental asset boundary of the revised SEEA-CF in a manner fully in keeping with its treatment in the SNA 2025. This would require expansion of the SEEA-CF classification of environmental assets to include an eighth asset. This asset would be accounted for identically to its treatment in the SNA 2025. This would reflect a choice of Option 2a regarding the inclusion of V-space in the revised SEEA-CF
- **Option 3b**—Include "Space for radio wave propagation" as a sub-entry under a new asset called "Space above land" in the asset classification. This would reflect option 2b (that V-space should be treated as its own asset in the revised SEEA-CF) and would further reflect the possibility—discussed in Section 3.3—that all of the value arising from spectrum auctions is due, in fact, to the use of V-space for the propagation of the associated radio waves and not to the existence of the radio wave spectrum itself (see Annex I for further discussion on this point). Choice of this option would put the SEEA-CF at conceptual odds with SNA 2025 regarding the spectrum—

[25] Sub-categories under assets for which no changes are proposed are not shown for the sake of brevity.

though, as noted earlier (Section 2.4.1), the SNA 2025 has put the possible reconsideration of the radio spectra asset on its future research agenda, so choosing Option 3a is no guarantee of future alignment either.

- **Option 3b_alt**—An alternative version of Option 3b (reflecting Option 2c above) is to add "Space for radio wave propagation" but as a sub-sub-entry under a new asset called "Space" with a sub-entry for "Space above land".
- **Option 3c**—Include both a new entry in the classification for "Space above land" with a sub-entry for "Space for radio wave propagation" plus a new entry for "Radio spectra". This option would reflect the view that both V-space and the spectrum itself give rise to the values realized in spectrum auctions (again, see Annex I and Section 5 for further discussion).
- **Option 3c_alt**: An alternative version of Option 3c (reflecting Option 2c) is to add is to add "Space for radio wave propagation" but as a sub-sub-entry under a new asset called "Space" with a sub-entry for "Space above land" and also to add a new entry for "Radio spectra".

Table 4 - Options for classification of the radio spectrum in revised SEEA-CF[26]

Option 3a	**Option 3b**	**Option 3b_alt**
1.Mineral and energy resources	1.Mineral and energy resources	1.Mineral and energy resources
2. Land	2. Land	*2. Space*
3. Soil resources	*3. Space above land*	*2.1 Space on land*
4. Timber resources	*3.1 Space for radio wave propagation*	*2.2 Space above land*
5. Aquatic resources	4. Soil resources	*2.2.1 Space for radio wave propagation*
6. Other biological resources	5. Timber resources	3. Soil resources
7. Water resources	6. Aquatic resources	4. Timber resources
8. Radio spectra	7. Other biological resources	5. Aquatic resources
	8. Water resources	6. Other biological resources
		7. Water resources
Option 3c	**Option 3c_alt**	
1.Mineral and energy resources	1.Mineral and energy resources	
2. Land	*2. Space*	
3. Space above land	*2.1 Space on land*	
3.1 Space for radio wave propagation	*2.2 Space above land*	
4. Soil resources	*2.2.1 Space for radio wave propagation*	
5. Timber resources	3. Soil resources	

[26] Sub-categories under assets for which no changes are proposed are not shown for the sake of brevity.

6. Aquatic resources	4. Timber resources	
7. Other biological resources	5. Aquatic resources	
8. Water resources	6. Other biological resources	
9. Radio spectra	7. Water resources	
	8. Radio Spectra	

4.4 Issue 4—Treatment of emission permits in the revised SEEA-CF

92. The final issue to consider is how emission permits might be considered in the revised SEEA-CF. As discussed earlier (Section 2.4.2), two economic interpretations of such permits are possible. On the one hand, they can be understood as Pigouvian taxes and on the other they can be seen as rights use V-space as a sink. This leads to the following three accounting options:

- **Option 4a**—Leave the treatment of emission permits unchanged, keeping it aligned with the SNA 2025. This would mean that cost of the permits would continue to be recorded as a tax on production. The implicit assumption behind this is that emission permits are intended by governments to operate as forms of Pigouvian taxes intended to internalize the externalities associated with excess emissions.
- **Option 4b**—Treat emission permits as payments for the rights to use an explicit V-space asset ("Space above land") as a pollutant sink, which would imply that they are a form of asset rental rather than payment of a tax. This option would correspond to selecting Option 2b above regarding the classification of V-space and would eliminate the SEEA-CF's alignment with the SNA 2025 on the issue. However, as noted earlier (Section 2.4.2), the SNA 2025 has already put the possible reconsideration of emission permits on its future research agenda, so choosing Option 4a here is no guarantee of future alignment either.
- **Option 4b_alt**—An alternative version of Option 4b (reflecting Option 2a above) is to not add an explicit asset for V-space to the classification, but to treat emission permits as payments for the rights to use the existing Land asset, recognizing that this asset includes V-space.

5 Recommendations on conceptual treatments

93. To come following discussion with Technical Committee members

- Propose recommendations to address the issue (based on the options described under section 3). As appropriate, note connections and potential implications for other issues being considered in the update process.
- Note that final recommendations on conceptual treatments will not be determined until after the Global Consultation process so the development of content in this section is likely to be more in the form of proposals for consideration, but this will vary from issue to issue.
- List the sections/paragraphs of the SEEA CF that need to change or where additional content is required

- Where possible and appropriate provide proposed text for inclusion in the revised SEEA CF (This content is not required for the initial drafts and, depending on the issue, it may not be possible to propose text ahead of Global Consultation, i.e. until there is more clarity on the option to be incorporated.)

6 Other considerations in advancing the issue

94. To come following discussion with Technical Committee members

- If relevant, propose **indicators** (and their derivation methods) that could be derived for this issue to support reporting and analysis
- Document **key terms and definitions** for inclusion in the SEEA CF Glossary
- Describe the existing **compilation guidance** and document what additional compilation guidance might need to be updated or developed (do **not** provide the guidance itself, that is not for inclusion in the SEEA CF)
- If relevant, describe **options for testing** the possible approaches. For some issues – e.g. for pressure accounts and sustainable finance, where the development of data and methods is less advanced, it may be useful for some countries to investigate and test the options proposed in section 3 to support determining the appropriate recommendations.
- Document any issues that remain unresolved as a result of the investigation or issues that have emerged as a result of the work that should be placed on the **research agenda** of the SEEA and potentially in relation to other statistical standards (e.g. SNA, BPM, etc.)
- For issues that are also being considered in the **GFS and COFOG revision processes**, describe the connections and potential differences in proposed treatments

References

Trenberth, K. E., and L. Smith, 2005: The Mass of the Atmosphere: A Constraint on Global Analyses. *J. Climate*, **18**, 864–875, https://doi.org/10.1175/JCLI-3299.1.

Annex I – Is the spectrum correctly categorised as a natural resource asset in the SNA?

95. Since it is germane to the present discussion, it is worth considering whether, in fact, the spectrum has the characteristics of a natural resource asset as was first argued in the SNA 2008 and continues so in the SNA 2025. A number of points are relevant.

96. First, given the subject of this Guidance Note, it should be noted that the *spectrum* has nothing to do with the *atmosphere* itself. As noted in Section 2.2.2, radio waves (and electromagnetic waves in general) do not require air or any other material to propagate. On the contrary, they propagate best in a vacuum and are hindered to a greater or lesser extent by the materials that constitute the atmosphere. Thus, when we are considering propagation of radio waves, it is use of V-space we are considering and not use of the atmosphere as such.

97. Second, it must be understood that the spectrum is not a quantitative, measurable "thing". It is, rather, an abstract concept, representing the specific range of frequencies of electromagnetic waves that scientists term "radio waves". Radio waves are, of course, quantifiable (they are forms of energy), but radio waves and the spectrum should not be confused—they are two different, though related, things. It should also be understood that while some radio waves exist *naturally* as a result of various phenomena out of human control (for example, lightning bolts), but the specific radio waves used in cellular telephone networks are entirely *artificial*. They are produced by radio equipment of various sources and would not exist if that equipment did not exist.

98. By convention, the radio wave spectrum is generally said to extend from about 3 kHz to about 3,000 GHz (ITU, xxx). Above and below these frequencies, various physical features of the waves themselves and of the natural world (including the just-noted fact that atmosphere itself is a hinderance to electromagnetic wave propagation, to the point of being entirely opaque to it at certain frequencies) limit the utility of radio waves for human communications. For this reason, the spectrum can be said to be scarce, as the number of usable frequencies is strictly limited (though, in fact, still quite large).

99. Third, spectrum auctions for cellular telephone networks cover only a small part of the economically important radio wave spectrum. Auctions occur only for specific frequencies found in that part of the spectrum where the frequencies used for cellular telephone transmission fall.[27] Today, those frequencies fall mostly in the 600 MHz to approximately 6 GHz range but increasingly—due to the arrival of 5G networks—frequencies in the 24 GHz to approximately 70 GHz range are also being used.[28] Spectrum auctions for frequencies above 24GHz (so-called millimetre-wave frequencies) are not yet common. Canada, for example, has not yet held its first millimetre-wave auction, though it has been auctioning cellular frequencies in the sub-8 GHz range since 1999 (ISED, n.d.).[29]

100. Other frequency ranges within the radio wave spectrum are of economic importance but not part of the "the spectrum" as defined by the SNA; that is, they are not frequencies that are the subject of auctions for cellular network frequencies. The most familiar of these frequencies are the traditional AM and FM radio bands, which cover frequencies lower than cellular frequencies; AM radio operates in the 540–1700

[27] For example, a list of the specific frequencies auctioned by Canada—an early adopter of spectrum auctions—since 1999 can be found here (ISED, n.d.).

[28] The number of individual frequencies included in spectrum auctions has increased over time, as new cellular telephone technologies have been rolled out allowing greater amounts of data to be carried at higher speeds. These higher data speeds can only be achieved by using higher frequency wavelengths (which comes at the cost of lower propagation—very high frequency radio waves only travel short distance because of interference from the atmosphere, buildings and other features of the planet's surface).

[29] For various reasons, frequencies between 6 GHz and 24 GHz are not particularly well suited to cellular communications today, though that could change in the future as technologies evolve. It is common today for 5G networks to use frequencies between 3 GHz and 6 GHz that were not used at all in earlier network generations.

kHz range, while FM operates in the 88–108 MHz range. Though there are auctions for these frequencies in some cases—especially in the U.S.—in many instances the frequencies are allocated to broadcasting organizations using a regulatory process. In any case, they fall outside the SNA definition of the spectrum (which focuses only on cellular network frequencies), despite their economic importance. Similarly, satellites broadcast at frequencies similar to those used for cellular telephones, but the frequencies used by satellites are not subject to auctions for various reasons and fall outside the SNA asset definition.

101. Fourth, as cellular telephone networks have evolved, frequencies that have been the subject of auctions in the past have been reauctioned through a process called "re-farming". For example, the 1900 MHz wavelength was commonly used in 3G networks in North America, but is now being reauctioned and repurposed to support the roll-out of 5G networks. This suggests that the specific frequencies within the spectrum used for cellular networks have, in some sense, the characteristic of renewability; that is, if they are natural resources, they may be more like forests than oil reserves.

102. Finally, there is no physical limitation on the "quantity" of radio waves that can be broadcast at any given point in space and time; at least, not in the same way as there is a physical limit on the amount of oil that can be pumped from a well or timber cut from a forest. However, there is a physical limitation on humans' capacity to make effective use of radio waves broadcast at any given point in space and time for telecommunications purposes.[30] This is because waves broadcast in the same vicinity and time can interfere with one another, reducing their utility for carrying telephone calls and data. This is why two radio wave emitters—say, competing cellular telephone providers—must be assigned different broadcast frequencies if they are to operate adjacent to one another—say, in the same city. However, because of attenuation of radio waves by the atmosphere and other obstacles, it is possible for broadcasters that are separated by a considerable distance—say, in two different cities—to be assigned the same broadcast frequency without concern for signal interference. This suggests that another limiting factor (that is, another source of the scarcity that gives rise to the asset) is the availability of V-space.

103. From the above, several things are apparent. First, the spectrum has nothing to do with the atmosphere, so we can rule out the existing recognition of the spectrum as a natural resource asset as a justification for considering the atmosphere an environmental asset in the revised SEEA-CF. Second, the "spectrum", as it is understood in the SNA, is actually just a few specific frequencies within a very large range of frequencies of radio waves. Most frequencies of radio wave are not used by humans for anything at all and many of the frequencies that are used are not subject to auctions (for example, those use for AM and FM radio broadcasts). Third, the radio waves used by cellular telephone to broadcast their signals are entirely human-made; there is nothing "natural" about them. Fourth, the specific radio frequencies used by cellular networks may be re-auctioned as network technologies advance, helping to eliminate frequency "scarcity". Finally, the physical limitation that induced governments to begin auctioning the right to use specific frequency bands within the spectrum for cellular communications is not a limitation inherent to the spectrum, but a limitation inherent to our ability to use specific frequencies within the spectrum at the same point in space and time without causing interference between users. This limitation is not fixed, but is, in fact, a function of technology. Thus, what is being auctioned in the case of the spectrum appears to be as much, if not more, the right to broadcast a human-produced radio wave of a specific frequency *within a specific area* of V-space; in other words, it is V-space that is the source of at least some of the scarcity and, therefore, is *at least* a joint asset with spectrum and, *possibly*, the primary asset in the case of cellular telephone networks.

[30] It should be noted that this limitation is not fixed but is, rather, a function of technology. Engineers and scientists have gotten better over time at extracting useful information (what they call "signal") from radio waves and reducing "noise" from interference between waves of similar frequency and other sources.

104. The above discussion is not meant to be definitive in terms of determining whether the spectrum is properly classified as natural resource asset in the SNA 2025. Settling this point would require a more detailed investigation. Moreover, it is not the objective of the present Guidance Note. Such an investigation may be unavoidable (though may not happen soon), however, since an apparent conflict between the SNA 2025's treatment of the spectrum and its general principles for rights to use natural resources was identified during drafting of the SNA 2025, though there was insufficient time to address it before finalizing the text. Its resolution has been added to the research agenda for the next iteration of the SNA, which will not likely appear until well into the 2030s.

105. That said, the discussion above does clarify that the SNA's treatment of the spectrum as an asset provides no justification for considering the atmosphere itself as an environmental asset in the revised SEEA-CF. It does, however, point to the need to recognize the V-space through which radio waves propagate as an asset.

Annex II – Aircraft overflight fees: Rent, payment for service or both?

106. Though payments made to operate an aircraft with a country's V-space could be considered either as payments for air traffic control services or as rent on the space, there would appear to be little evidence that they are the latter. If such payments were rent, a country could provide no services of any sort to overflying aircraft but still charge overflight fees. But every country provides a range of air-traffic control services and keeps track of planes that enter its airspace, even those that are simply overflying. An overflying plane knows that it could, in an emergency, land in any country it overflies and receive assistance (or else it wouldn't overfly it) and understands that the overflight fees are the cost of assuring that assistance. So, no country simply tries to collect rent on its airspace by charging overflying airlines a fee in return for nothing more than the right to overfly.

107. In Canada, for example, a non-profit private organization (previously a government body) known as NAV Canada that collects these fees as part of the revenue it needs to operate Canada's flight navigation system. If Canada's V-space were to be recognized as an asset on which overflight fees were considered rent, then NAV Canada would be the economic owner of that asset. Canada's V-space would have to appear on NAV Canada's books, which it almost certainly does not. Rather, the assets that would appear on NAV Canada's balance sheet would be limited to the equipment and infrastructure needed to provide air traffic control (for example, the 1400 navigation aids it manages across the country).

108. The situation is pretty much the same in the UK, though it is a private (for profit) company half owned by the UK government providing the services. In Australia, a wholly government-owned corporation does so.

109. These air traffic control companies are quite different from the mining companies that are the legal owners of mineral deposits. Mining companies do record deposits on their balance sheets and do expect a return to them to cover the cost of their acquisition.

110. A more detailed investigation would be required to determine whether there are countries in which aircraft control fees include a component of rent and, if so, what share of the total available rent is captured. What is important here is that the capture of such rent is at least a theoretical possibility, which supports the general position taken in this Guidance Note that V-space is a valuable environmental asset.