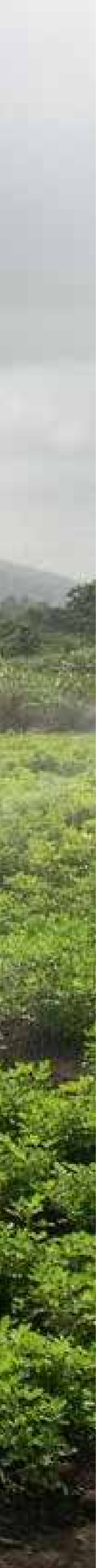

6. Economic impact assessment framework for sand and dust storms

Chapter overview

This chapter discusses different approaches to assessing the economic impact of sand and dust storms (SDS). The chapter begins with a review of research into SDS, followed by an extensive discussion of the different types of costs which need to be considered when assessing the economic impacts of SDS. This is followed by a review of the different methods which can be used to assess economic impacts and an extensive discussion of the cost-benefit (or benefit-cost) method as applied to SDS. The chapter concludes with a review of the data sources which should be used in the cost-benefit method and in the overall assessment of the economic impact of SDS.

6.1 Damage, costs and benefits of SDS

6.1.1. Reviewing the costs and benefits of SDS

Sand and dust storms (SDS) differ from many other disasters in that there is usually very little major structural damage. The physical damage caused by SDS is relatively minor when compared to other disasters such as earthquakes or floods.

SDS do not usually result in directly attributable fatalities or injuries, with most health-related impacts associated with other health conditions such as respiratory diseases, eye problems or cardiovascular diseases. However, SDS can be the proximate cause of fatalities and injuries due to transport accidents, most commonly road accidents in conditions of high sand and dust.

The most evident damage caused by SDS is impacts on the natural environment due to, for instance, dust and sand accumulation or inundation on croplands. Sand and dust can also affect infrastructure operations by entering commercial, manufacturing or residential structures, leading to productivity- or production-related issues, as well as the need for cleanups, removals or limiting economic activity. Neither the human nor the financial impacts of SDS are well captured in international disaster databases, such as those maintained by the Centre for Research on the Epidemiology of Disasters (see **chapter 3**).

The economic impact of SDS is somewhat unique, in that there is a cost at the source of the sand or dust emission through losses in soil and/or sand and associated losses in productivity or income. In areas where there is no direct economic activity, indirect costs will still be incurred through loss of soil nutrients or carbon, and perhaps ecosystem services. There are also costs imposed on the region downwind of the emission region, due to economic disruption caused by the event(s), such as closure of transportation services and cleaning of roads, houses and business premises (Huszar and Piper, 1986; Tozer and Leys, 2013).

The impact of SDS can be mitigated at the source with investments in soil and land management practices, such as using forestry or cover crops to reduce soil losses or movement of sand when weather conditions could lead to an SDS event. Furthermore, the effect on the downwind region can be reduced with mitigation practices such as installation of air filtration systems or early warning systems to ensure that members of high risk populations remain indoors.

However, the net benefits and/or costs of mitigation, either at the source or in the impact region, need to be considered in the context of the overall cost of SDS to an economy. This consideration needs to take place either in a region within a country (such as a province, state or set of states), country or global region (including several countries), such that the benefits of mitigation outweigh the costs.

Measuring the impact of SDS for each country is critical as it allows the government of a country to determine if the costs of SDS can be moderated through an investment in mitigation projects within the country in the source area. The key aspect here is that the benefits of dust mitigation outweigh the costs of the mitigation measures, recognizing that the control of all SDS impacts may be not feasible from a financial perspective.

It is important to recognize that most benefits of mitigation will accrue to individuals, but most of the costs are incurred by the government or government agencies. Thus, even though there may be a net benefit, the funding agency may not have sufficient funds to finance the mitigation programme. What must also be remembered here is that the objective is to reduce the effects of dust on the population in the impact region, not to eradicate SDS completely, as SDS are part of the natural cycles of the world and therefore total removal of SDS is undesirable from a total environmental perspective.

Dust mitigation projects may also be undertaken in source regions outside the national boundaries of a country, as airborne dust particles have been shown to travel long distances, hence there can be a significant distance between the source region and the impact region. As a result, the benefits and costs of a mitigation programme may fall on, or be incurred by, different countries or regional government instrumentalities. However, the major decision criterion is that the net benefits of the programme (the sum of benefits in both the impact and source regions) exceed the costs.

There are numerous approaches to measure the economic impact of SDS and to measure the costs and benefits of mitigation programmes. To that end, this chapter presents a method of measuring the costs of SDS on the impact region and provides a framework to measure the costs and benefits of various mitigation strategies in either the source or the impact regions.

6.1.2. Previous economic impact studies

Given the prevalence of SDS around the world, the number of economic impact assessments is very limited. In one of the first attempts at measuring the economic impact of SDS, Huszar and Piper (1986) used surveys of businesses and households to quantify the off-site costs of sand and dust storms in New Mexico, in the United States of America (USA). Huszar and Piper (1986) estimated the costs of SDS in New Mexico alone were approximately $857 million (in 1985 dollars). This is only the cost to households and businesses and does not include other costs such as the removal of sand and dust from roads by city, county and state transportation authorities, nor does it include defence force costs for cleaning airbases located in the state.

In a study of the costs of wind erosion, or SDS, in South Australia, Williams and Young (1999) estimated the annual average costs of SDS events to the population of that state was $A 23 million (in 1999 Australian dollars). Most of the cost ($A 20 million) was health related. The range of costs estimated by Williams and Young (1999) was from $A11 to $A56 million.

Ai and Polenske (2008) used Input-Output (I-O) modelling to estimate the costs of SDS in Beijing in 2000. The authors concluded that the delayed impacts of SDS exceeded the immediate effects. Delayed impacts are those that do not occur on the day(s) of a dust event but are consequences of the dust storm. Immediate effects occurred in the construction, trade and household sectors, and totalled $US 66 million. Delayed effects on the agricultural and manufacturing sectors totalled US $198 million. Together, the total economic cost of SDS was $US264 million (in 2003 dollars).

Miri et al. (2009) estimated that SDS cost the Sistan region of eastern Iran US$ 125 million from 2000 to 2004. Most of the costs – 61 per cent – were reportedly related to household cleaning and reduced electronic equipment life. A further 25 per cent were associated with the cost of health-related issues, including hospital admissions.

Measuring the economic impact of one significant dust storm in New South Wales, Australia, Tozer and Leys (2013) estimated the costs to be $A299 million (range of $A293 to $A313 million in 2012 Australian dollars) in that state alone, without measuring the impacts on other states which experienced the dust storm. Most of the impact was on the household sector, with 85 per cent of the costs. The next two most impacted sectors were transport (principally air traffic) and commercial activity.

SDS economic impact was studied in Kuwait, with the impact on the oil and gas operations estimated to cost $US 9.36 million in 2018 (Al-Hemoud et al., 2019). Also, oil export losses due to closeout of marine terminals were estimated at US $1.03 million per ship (Al-Hemoud et al., 2017). Airline delays due to airport operations shutdown were also estimated.

6.2 Types of costs in the context of SDS

6.2.1. Direct and indirect costs

Several researchers define two types of costs associated with disasters – direct and indirect (see, for example, Hallegatte and Pyzyluski, 2010). Direct costs are those associated with the immediate impact of a disaster. In the context of SDS, most costs are direct costs, as the impacts of SDS do not typically have long-term effects on an economy in the same way as damage and reconstruction caused by hurricanes and earthquakes does, requiring rebuilding of damaged structures and functions within the economy of the affected area.

Indirect costs are those that are imposed on an economy due to business disruptions or other similar impacts brought on by a disaster. As noted, SDS do not have a long-term impact on most of the economy. A thorough review of the economic impact studies related to SDS events is presented in Al-Hemoud et al. (2019).

One set of indirect costs that SDS may impose on an economy is due to the long-term loss of income for landowners in the SDS source region(s). Depending on the level of loss, indirect costs may exceed direct costs in some regions. From a socioeconomic perspective, this can have long-term impacts, particularly if the costs push a vulnerable population past a critical threshold.

6.2.2. Market and non-market costs

Market costs are those costs that can be directly estimated due to a market for a product or that can be estimated using a market valuation technique. In the context of SDS, many of the damage costs can be estimated using market cost, in that there are established markets for the products or services affected.

Non-market costs or values are for damage or products for which there is no direct market. Examples of products or damages that fit into this category include damage to cultural icons or historic sites, environmental or ecosystem services, or human lives.

There are some ways to measure the economic impact of events on human life, such as disability-adjusted life years (DALY) or quality-adjusted life years (QALY) (World Health Organization [WHO], 2016). However, these are used as an index for the value of all lives and do not take into account many social, cultural and economic factors (Arnesen and Nord, 1999). There are also accepted methods to estimate non-market values for environmental services or loss in revenue from cultural or tourism events, such as contingent valuation (willingness to pay) or travel costs (Hanley and Spash, 1993; Harris, 2006; Ninan, 2014).

6.2.3. Cost and value

One important distinction to make is the difference between cost and value. A 'cost' is how much a person has to pay for a product, or the price of that product, which is usually reasonably easy to observe in a marketplace. In contrast, 'value' is somewhat subjective, and is a measure of what a person would be willing to pay for a product or service that may not have a fully functioning market.

> The key difference here is what a person has to pay against what they are willing to pay. In the context of SDS, much of what is discussed in the following sections will be a cost-based analysis. However, when discussing effects of SDS, such as damage to cultural icons or reduction in ecosystem services, methods of assigning value to these types of services will also be discussed.

6.2.4. On-site (source) and off-site (impact)

SDS create damage in two locations, the source location and impact region. The economic impact in either location will depend on many things, such as the level and types of economic activity in either region, the activities undertaken in the source region that may contribute to SDS events, such as farming or cropping, the relative wealth of the population in each location and damage to the environment or ecosystems in either location. Other factors that need to be considered include damage to environmental or ecosystem services in either region, or the human aspects, such as health and income distribution in the source and/or impact region.

6.3 Gender, age, disability and economic analysis

Gender, age and disabilities are important to consider in assessing the economic cost of SDS. Specific impacts may be greater for men, women, boys or girls due to their social or economic situations. For instance, if men are obliged to work outside in areas where SDS are common, then impacts on their health could be significant and could have an impact on how long or how often then can work.

Similarly, age and disability are factors in some of the health impacts of SDS. For instance, older persons are potentially more vulnerable to respiratory or cardiovascular conditions which can be exacerbated by SDS. These SDS impacts may increase health care costs, require other family members or hired help to assist the affected or take affected persons away from productive activities.

To the extent that disaggregated data are available, economic assessment results should identify the extent to which SDS impacts affect different gender, age and disability groups in terms of participation in, and benefiting from, the economy. This type of analysis can be useful in tying statistical analyses used in economic impact assessments to real challenges faced by SDS-affected groups.

6.4 Economic impacts of SDS

6.4.1. Impacts to consider

Research on the economic impact of SDS has focused on the direct impacts on the main drivers of an economy, such as transport, manufacturing or the costs of cleaning incurred by households and industry (Huszar and Piper, 1986; Tozer and Leys, 2013).

However, two other major components in a society can be significantly affected by SDS in either the source or the impact region. These are (i) the environment or ecosystem within a region or country and (ii) the human dimension, beyond losses of income due to lower production or sales. However, the key concept here is that the three components; economic, environmental and human, are all tightly interlinked, meaning that they cannot be easily separated when measuring the overall economic impact of SDS.

The impacts of SDS on the economic activity within a source or impact country or region are relatively easily measured and in most cases are direct costs, with some minor indirect costs. Environmental or ecosystems services can be severely affected by SDS in either the source or the impact region, depending on the environment or ecosystems in each region.

In the source region, soil erosion, damage to waterways and/or habitat or ecosystem loss or damage are some of the consequences of SDS emissions. Air quality, waterways siltation and ecosystem damage are some of the environmental consequences in the impact region of SDS.

The human side of the impacts of SDS are a little more complex to disentangle due to differences across regions or countries from which SDS are sourced and/or impacted. The reasons for this are due to (i) the complexity of economic welfare and equality in the source and/or impact regions and (ii) how erosion of the soil – the source of material for SDS – affects the livelihoods of those relying on it as a source of food and/or income.

Another reason for this complexity is that soil erosion is a dynamic factor affecting production and productivity of land in the source region. Incomes are not only affected in one year by soil erosion. If erosion continues, then production – and, by extension, incomes or wealth of the population in the source area – will be continually reduced until the soil is unable to sustain any cropping activities at all, hence reducing food supply or landowner income on the affected land to zero.

Another aspect of the human side of the impact of SDS is the health of the population, at the source or, more commonly, in the impact region, in that dust has been shown to negatively affect certain segments of the population. This is a somewhat complex situation. An SDS event may trigger a health crisis leading to a fatality, but attributing this fatality to SDS may be difficult, for several reasons. The person may have had a history of health problems before the SDS event, such as cardio-pulmonary issues. This places them in a high-risk category. There may have been a significant timespan between the SDS event and the health effect.

Similar issues exist in the case of non-fatal health events, such as an acute case of difficulty breathing which required hospitalization (and thus lead to costs). However, SDS may not be the only factor in the hospitalization and therefore untangling the costs that can be attributed to SDS becomes difficult.

Another human impact of SDS is the loss of life or increased care for people injured in transport accidents, most often air- or land-based in nature. Calculating the economic impact is challenging, as there is a need to consider the health impacts (fatalities, injuries) as well as the loss of goods and services due to the accident. While an accident itself may be very location-specific – for instance, closing a section of a major highway – the knock-on effects on changes in traffic patterns (for example, redirecting commercial trucks onto alternate routes) can be hard to capture using available data.

Finally, the health conditions triggered by SDS events will vary across populations, due to factors such as gender, age, income and wealth, nutrition access and availability, as well as the ability to avoid dust events through housing and/or ventilation. Distinguishing these variations in conditions of SDS-affected individuals can be difficult when the data available is limited in coverage or detail.


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6.5 Identifying the damage and costs of SDS

6.5.1. On-site costs – economic activity

On-site damage is usually in the form of loss of soil and sand, which leads to scalding[1] of the site. Associated with the loss of soil or sand is the loss of soil nutrients and organic matter including soil carbon (Leys and McTainsh, 1994; Leys, 2002). This loss of soil or soil nutrients reduces the productive capacity of the soil, and thereby potentially reduces the income for landowners or land users, with the impact varying based on the location, economic and political context of the region (Economics of Land Degradation [ELD] Initiative and United Nations Environment Programme [UNEP], 2015).

Further costs are incurred in the source region due to damage to infrastructure such as irrigation or water systems, destruction of fences, loss of livestock and forage for livestock, sandblasting of crops and road cleaning. Dust can also contain soil carbon, which could have a value to the landowner, particularly if in the future carbon sequestration and carbon markets become more functional.

Huszar and Piper (1986) suggest that an approximation of the immediate on-site costs of wind erosion, such as damage to infrastructure, can be obtained from the off-site costs. Using the method proposed by Huszar and Piper (1986), a value of 2 per cent of the costs of household cleaning can be used as the basis for determining on-site costs based on the calculations.

Using this method, Tozer and Leys (2013) estimated on-site costs of approximately $A 5.1 million for a single severe dust storm that affected eastern Australia in 2009. The estimated cost was consistent with the Natural Disaster Relief Assistance request of $ A4.5 million to compensate landowners for costs and losses due to the event (Kelly, 2009).

However, the method used by Huszar and Piper (1986) does not account for the long-term loss in productivity or income due to soil erosion and soil nutrient loss, and may only be appropriate in situations where productive land is the source area, such as in remote grazing regions, like central Australia or the southwest of the USA. ELD Initiative and UNEP (2015) provide an approach that can measure the loss in production and income due to soil erosion in general, but the methodology can be applied to countries where SDS originate, as some of the losses in soil and/or sand are due to anthropogenic activities, such as agriculture or deforestation.

6.5.2. Off-site costs – economic activity

Off-site costs of SDS will depend on many factors, with the principal factor being the level of economic activity in the impact region. For example, SDS that affects mainly agricultural or pastoral regions may not have as much economic impact as SDS that affects a major metropolitan area. The main reason for the difference in impact across different regions can be attributed to the level of infrastructure in the different regions and the relative populations.

Major urban centres are more affected by SDS than less populated rural areas. This is simply due to the higher amount of the population that are subject to health impacts, the level of wholesale, retainment of commercial and industrial activities, and disruptions caused by SDS impacts on traffic or the provision of education due to school closure or restriction of outside activities in these urban areas. Implicitly included in the costs incurred within many sectors, including commerce, manufacturing, transport and the public sector, is the cost of cleaning or removal of sand and/or dust from impacted locations.

1 See https://www.qld.gov.au/environment/land/management/soil/erosion/types for a definition.

Transport

Major cities tend to have more key transport infrastructure than regional centres, including airports and airline hubs with significantly higher aircraft movements, rivers, seaports and road transport systems. Any factor that limits capacity or vehicular movement can cause substantial economic losses.

Costs to the various transportation subsectors vary due to the types of impacts. The airline industry is affected as SDS typically reduces visibility, making landing and taking off difficult. This can lead to aircrafts being grounded, leading to flight delays, cancellations or diversions.

An SDS event can have several impacts. Airlines will lose income through reduced passenger numbers, with some passengers receiving fare refunds. Aeroplanes will need to be diverted if they cannot land at an affected airport. Following diversions and delays, aeroplanes will need to be repositioned to ensure the schedule returns to normal after the SDS event.

In some cases, airlines will provide food and/or accommodation for passengers that are affected by delays or cancellations or provide alternative means of transport to their final destination (Williams and Young, 1999; Tozer and Leys, 2013).

Although water transport may not be as severely affected by reduced visibility as the airline industry, it may cause port and ferry services to be reduced (Tozer, 2012). Also, port services may be affected through increased loading or unloading times due to worker health and safety issues. For instance, dust may cover surfaces, making them unsafe to work on. A reduction in port processing time could add costs such as demurrage to the total costs for a ship owner or charterer.

The impact on the road system can be a significant cost. The effects of SDS on road transport are:

- **road closures due to either visibility or dust or sand on the road surface**
- **traffic accidents due to surface or visibility conditions**
- **reduced transport requirements as a knock-on effect from reduced activity in other sectors, such as the construction industry**

Dust storms have been shown to directly lead to traffic accidents in, at least, Australia, Iran and the USA (Williams and Young, 1999; Burritt and Hyers, 1981; Miri et al., 2009).

Two aspects that can affect the costs of road transport are:

- **travel speed during SDS**
- **the number of vehicles on the road during an event**

These two aspects affect travel time for road users. Travel speed may be reduced due to poor visibility during a dust storm, but if some employees or parents remain at home during the event, the number of vehicles on the road system may be reduced (Tozer and Leys, 2013). As a result, the impact on travel speed and transport costs may be difficult to estimate.

Health

The health impacts of SDS are difficult to measure and to assign a cost to, due to the differences in reporting across countries or regions and differences in analyses of data. In a review of 50 papers reporting health effects due to dust or poor air quality, de Longueville et. al. (2013) found mixed results as to whether health was impacted by atmospheric dust or poor air quality.

One issue that arises in much research related to the health impacts of dust is attribution of effect. For example, an at-risk portion of the population, especially those with pre-existing cardiopulmonary issues, may have a higher mortality or morbidity rate during a dust storm due to the atmospheric dust exacerbating the pre-existing condition.

The issue then becomes whether the dust is the cause of the mortality or morbidity or simply the final contributor that leads to the death (de Longueville et al., 2013). Huszar and Piper (1986) estimated that the health costs to households of a series of SDS events were approximately US$ 19 million out of the total household cost budget of US$ 458 million. Tozer and Leys (2013) did not find any significant health effects of the Red Dawn event in Australia in 2009, but this may be at least partially attributed to an early warning system in place for at-risk populations. However, the health costs estimated are only the direct costs to households and do not capture the effects on society of reduced health due to SDS.

Household cleaning

Previous research has shown that households face the highest direct costs of SDS due to interior and exterior cleaning, as well as repairs and maintenance of structures and vehicles (Huzsar and Piper, 1986; Tozer and Leys, 2013). Miri et al. (2009) found that household cleaning costs accounted for over 85 per cent of the total costs estimated for dust storms in the Sistan region of Iran. In assessing household cleaning costs, the value of time and resources used, as well as income opportunities lost or deferred, need to be understood in terms relative to the economy and level of income where these actions are taking place.

In many cultures, household cleaning is a task allocated to women and girls. The additional work needed to clean up after an SDS event could increase overall workload for women and girls and reduce opportunities to otherwise gain income or non-monetary assets (for example, from the collection of natural resources).

Commerce and manufacturing

Measuring the effect of SDS on the commercial sector is fraught with challenges. Some expenditure that is not made during an SDS event may be made after, meaning that there is no loss in income for some commercial operators. This is especially true for food and essential items purchases made by households, as the purchases are simply delayed rather than not made, and only delayed for the duration of the event.

However, time-sensitive purchases, such as newspapers and perishable or fresh foods like bread or fruit, may not occur during the SDS event. The absence of these purchases will cause retailers to lose revenue and the product(s) to be discarded. Similarly, discretionary purchases by consumers, such as takeaway coffee, may not be made, again reducing retailer income (Tozer and Leys, 2013). Other indirect costs may be incurred in the commercial sector due to delays in delivery of goods required for production or movement of goods out of production facilities.

The manufacturing sector may be affected by SDS if the particulate matter enters the manufacturing facility, or through delays in material required for production being held up in transit. For example, electronics component manufacturers in Korea noted that on days of high particulate matter, more faulty products or faults in final components were observed (Kim, 2009).

Another cost of SDS in the commercial sector is that of absenteeism, or employees being absent to care for children (if schools are closed during an SDS event) or others in need of care. Absenteeism has been shown to reduce productivity, and as a consequence of the SDS event, must be added to the cost. A point to consider is that only the loss of productivity should count towards costs incurred as a result of the SDS event, as costs of production should include costs of workers taking leave for various reasons (Tozer and Leys, 2013).

Agriculture

SDS can impose costs on the agricultural sector through:

1. Crop destruction or reduced yield
2. Reduced animal production due to animal death or lower yields of milk or meat

Ai and Polenske (2008) estimated that the impact of SDS on the agricultural sector in the Beijing region in 2000 was the second highest only to the manufacturing sector and constituted about 36 per cent of the total cost in that year.

For annual crops, losses are due to sand or wind blasting and can lead to complete loss of crops in a particular region or a reduction in yield due to partial losses. The impact on perennial crops could be similar to annual crops in that the current year crop could be lost or reduced. However, there may also be a longer-term effect on some perennial crops due to tree or crop damage (for example, Lucerne/alfalfa crowns being damaged), leading to reduced production in future years.

Animal production can also be affected in several ways. There may be a reduction in milk produced during the SDS event, thus costing the producer income with no compensatory reduction in costs. The SDS may lead to the loss of animals, either through death (particularly through suffocation in severe events) or through producers being unable to locate them after they fled the SDS event. An animal producer may also face lost, destroyed or damaged feed stocks, pasture or forage crops, requiring the producer to purchase feed that they would otherwise not have done.

Other costs

Other costs of SDS in the impact region include:

1. Reduction in construction and mining activity, due to health and safety issues at the construction or mine site
2. Increased emergency service activity, due to road or traffic accidents or ambulance traffic transporting patients to hospitals due to dust-related health problems
3. Damage to utility infrastructure such as electricity transmission lines or pylons

In some cases, SDS may lead to damage, but there may already be pre-existing conditions that contributed to the final damage caused by SDS.

SDS can also impact cultural, leisure and sporting activities and the cost to the economy will depend on the type of event affected. Estimating these costs can sometimes be difficult, particularly if the event is a one-off event such as an outdoor music concert.

The closure of schools and educational establishments due to health concerns can also impose costs on the economy. However, many of the costs will be captured in other estimations.
The costs of carers remaining at home because of SDS events will be captured in the absentee estimation and reduced transactions at commercial establishments will be gathered in the retail/wholesale sector calculation.

As noted earlier in **chapter 6.2,** there are different costs associated with SDS, and there are also different or more appropriate valuation methods for some of these costs – market or non-market valuation. **Table 7** presents a brief overview of some of the costs covered earlier in this section and appropriate methods of estimating or valuing these costs. For some costs, such as health or water resources, the total impact of costs may be estimated using a combination of methods, due to the differing impacts across sectors and the population.

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6.5.3. Off-site benefits

Typically, there are few immediate benefits offered by SDS events, and in the context of the overall costs and benefits of SDS, off-site benefits are usually relatively small when compared to off-site costs. Benefits of SDS arise from two main sources – nutrient deposition on land and nutrient and mineral deposition in water, particularly ocean bodies.

SDS dust content can contain soil nutrients, such as nitrogen, phosphorus and potassium, as well as organic carbon. When deposited, these can provide nutrients to crops or pasture downwind of the source area. Leys (2002) estimated that dust deposited after a dust event contained 0.0034 g/m^2 of total nitrogen and 0.0008 g/m^2 of total phosphorus. Nutrient and mineral deposition in ocean bodies can provide nutrients to phytoplankton, which in turn can increase fish stocks, as phytoplankton are in the lower levels of the ocean food chain (Cropp et al., 2005).

The benefits of soil carbon deposition are more difficult to estimate due to the need for a value for carbon in the system where the deposition occurs. The challenge in terms of estimating the benefits is determining the overall dynamics of the food chain and the time for any increase in phytoplankton to flow through to the upper levels of the food chain where economically viable populations of fish are located. Iron contained in dust can also lead to increased carbon sequestration by phytoplankton as well (Blain et al., 2007). Again, the amount and value of carbon sequestered is difficult to estimate and beyond the scope of the current study.

One point to note here is that some degree of dust movement is an integral and natural part of the earth system. This deposition brings benefits as well as hazards to human communities (Middleton and Goudie, 2001). Total removal of dust movement is undesirable and probably extremely costly in terms of ecosystem losses.

Table 7. Examples of costs and valuation methods for measuring impacts on various economic activities

Economic activity	Cost type:		Valuation type:	
	Direct	Indirect	Market	Non-market
Transport	Airline delays and cancellations	Rail or road delays due to closures	Usually market-based	
Health	Hospital admissions	Decrease in health of individuals over time	Direct expenditures on health-related costs	Mortality or morbidity costs on society – can use disability-adjusted life years or other measures but not market-based measures
Cleaning – Household and commercial	Direct cost	NA	Market costs of product and time	NA
Commercial or manufacturing	Loss of sales or production during dust event	Reduced, or loss of, sales due to inability to get product to market or get inputs into manufacturing plants	Market costs of lost sales in both direct and indirect cases	NA
Agriculture	Loss of marketable product; delays in harvesting at optimal time	Delayed regrowth of perennial crops, or loss of product due to delays in planting at optimal time	Market costs of lost production in current or future crops	NA
Water resources	NA	Dust deposition in water ways, i.e. rivers, canals etc.	Cost of dredging or dust/mud build-up	Losses in services in the future, such as water access or availability; effect on fish or other populations affected by build-up
Ecosystem services	Loss of use during event	Dust deposition in ecosystem, i.e. on plants	Loss of income by service providers	Most costs will be valued using non-market techniques, such as travel cost or contingent valuation methods

6.6 Methods to assess the economic impact of SDS

6.6.1. Overview of model types

The assessment of the economic impact of SDS can be undertaken using a variety of methods, from relatively simple accounting-type methods to more complex econometric or mathematical programming models (Cochrane, 2004).[2] The methods can be categorized as follows:

- combined econometric and optimization models – computable general equilibrium (CGE), partial equilibrium (PE), or other generic econometric and simulation models
- linear programming models – Input-Output (I-O) models
- survey methods and analysis
- accounting-type models
- hybrid models

These models have been used to measure the economic impact of SDS or other disasters. Their applicability or usefulness in assessing the economic impact of SDS depends on available data, the type(s) of event, and assumptions made. Table 8 briefly summarizes each methodology, data requirements and analytical skills required to undertake an economic assessment of SDS using each methodology.

Computable general equilibrium (CGE) models have been used to analyse the impact of disasters on economies but have not been used to study SDS impacts (see, for example, Rose and Lim, 2002; Rose and Liao, 2005). As the name implies, CGE models are models of a whole economy, including households, firms and government (through taxation submodels).

The model is based on the social accounting matrix (SAM) for that economy. A SAM captures all the interactions between the various industry sectors within an economy, including households, firms or businesses, and where necessary, governments through the impact of taxation on costs of production and incomes.

These types of models rely heavily on the parameterization of the models and price changes to measure the impacts of perturbations to the economy, such as disasters or changes in taxation policy, and how they affect the whole economy. However, the impact of SDS on prices or changes in interactions between sectors, as measured by the SAM, is difficult to do given the frequent nature of SDS events, within a year and over many years (Cochrane, 2004).

Input-Output (I-O) models, which are similar to the CGE models, rely on the SAM to measure the interactions between industry sectors. As a result, they have very limited flexibility to deal with changes that occur within a year – changes which may not significantly impact interactions between sectors.

Another problem with CGE or I-O models in the analysis of SDS is that to measure the impact, the SAM or parameters of the model rely on changes from a base scenario which is perturbation-free. However, as noted earlier, because SDS occur frequently within and across years, identifying a counterfactual base is very difficult.

One aspect that the SAM – and therefore I-O or CGE models – does not capture due to the non-market valuation is the value of the environment or ecosystem services, except through transactions such as cleaning costs or travel costs to an environmentally sensitive destination. These types of models do not typically have the ability to capture the impact on humans of SDS, either through mortality or morbidity or changes in the distribution of wealth or equality.

2 A full comparison and motivation for any one type of model is beyond the scope of this chapter. Readers interested in a more complete discussion should consult the references provided at the end of the chapter.

If measuring the impact of SDS across a region, either within a country or across several countries, a model of the region or each country in the region is required. In some countries these types of models are available, for example, studying the effects of SDS on Beijing, Ai and Polenske (2008) used a regional I-O model to estimate the impact of SDS.

Surveys have been used in previous analysis of the impact of SDS (Huszar and Piper 1986). Surveys are typically limited to certain segments of the economy, such as households or businesses, and may not capture the interrelationships between industry sectors.

However, surveys are useful in identifying specific costs or types of costs, as shown by Huszar and Piper (ibid.), who surveyed households and businesses in the state of New Mexico in the USA and identified household costs down to specific categories, such as exterior painting, landscaping, interior cleaning and laundry, and automotive damage. However, Huszar and Piper (ibid.) did not survey transportation agencies or firms, or public agencies such as the state Department of Transport or the emergency services. Therefore, the costs of the dust storms may be underestimated.

Tozer and Leys (2013) and Williams and Young (1999) used an accounting-type framework to estimate the costs of dust storms in two Australian states. The studies utilized the survey data of Huszar and Piper (1986), adjusted for the situation and differences in frequency of SDS and exchange rates, to measure some of the impacts of SDS.

This approach requires complete identification of all costs and the ability to source the required data to enable full costs of SDS to be measured. Also, this type of analysis needs to ensure that interactions between sectors of an economy are captured. Care needs to be taken to ensure double counting of costs is avoided (Cochrane, 2004).

Cochrane (ibid.) identifies one other type of tool to analyse the impact of natural disasters, and this is what he terms "hybrid models". These types of models are usually disaster-type, case, country or region-specific and are criticized for being somewhat ad hoc.

An example of this type of model provided by Cochrane (ibid.) is the HAZUS model that is used to simulate indirect economic losses from natural disasters such as floods or earthquakes in the United States. Cochrane (ibid.) indicates that hybrid models can also include combinations of two of the model types discussed earlier, providing they are well constructed and allow for sound loss accounting, and that they are reasonable models to use in calculating economic costs of natural disasters.

6.6.2. Data requirements

One crucial aspect of selecting a tool to analyse the economic impact of SDS in a country or region is the availability of the required data. Where possible, the data used should enable a disaggregation of impacts by gender, age and disability.

Techniques such as CGE or I-O require sufficient data to construct the SAM, therefore data that shows all the interactions between segments in the economy is needed. This implies that significant industry level data are required as being able to measure the interactions between sectors and measuring the substitutability of production across sectors is a requirement for the SAM. Other methods, such as the cost accounting or survey method, do not require as much data as CGE or I-O, but do still require significant amounts of data, some of which can be difficult to identify and collect, such as household costs, reductions in retail sales, or consumer willingness to pay for environmental damage.

For the accounting method that uses survey data – or the survey method itself – it is necessary to identify the survey population, and from within that population, the survey sample. This should inform the design of the survey, which also requires a pilot test. Then, the data must be collected and analysed.

A similar approach is required for the non-market valuation studies, in that surveys or other similar research tools need to be developed to collect the required data to value environmental or ecosystems loss or damage.

Table 8. Summary of methodologies, data requirements and skills required

Impact methodology	Data requirements	Analyst skills	Strengths of method	Weaknesses of method	Applications to sand and dust storm impact analysis
Computable general equilibrium (CGE)	Very high – need data set including the entire economy.	Very high – need to be able to construct a social accounting matrix.	Good for single event analysis.	Need a control year.	No applications to sand and dust storms. Has been applied in single event disasters: Rose and Lim (2002), California earthquake; Horridge, Madden and Wittwer (2005), Australia drought.
Input-Output (I-O)	Very high – need data set including the entire economy.	Very high – need to be able to construct a social accounting matrix.	Good for single event analysis.	Need a control year.	Ai and Polenske (2008), impact of sand and dust storms on Beijing.
Surveys	Medium – need a good response rate to surveys.	Medium, but high with respect to survey design and sample selection.	Simple; easy for low-skilled analysts. Can extrapolate single events to multiple events.	May be costly to gather sufficient quality and quantity of data for complete analysis.	Huszar and Piper (1986), impact on New Mexico of multiple sand and dust storm events.
Hybrid	Medium–high.	Medium–high – need skill to identify data and data gaps.	Relatively simple; can capture whole impact, providing there are no data gaps. Can extrapolate single events to multiple events.	If there are data gaps or poor data-collection, very poor results.	Tozer and Leys (2013), Single event sand and dust storms in Australia; Miri et al. (2009), multiple events in Sistan region of Iran.

6.7 Factors to consider in selecting ways to measure economic impacts of SDS

6.7.1. Challenges to be addressed

The principal challenge in measuring the economic impact of SDS is not the physical, that is, not the type of SDS event or the geography or geology of a region or country. The main challenge is ensuring all relevant and consistent data are identified and collected, and that the economic impact is measured relatively accurately.

It must be remembered that any measure of economic impact will be an estimate. Any measures of impact will have some degree of error due simply to the data-collection and analysis process, and the time delay for some impacts to flow through an economy.

The more differentiated economic activity is within a country, the more data are required to fully measure the impact of SDS. One point to consider here is that SDS may not impact all economic sectors in an economy or a country due to the geographic concentration of SDS, thus reducing the need for a full set of economic measures or data for the whole economy, only those sectors impacted.

Another limitation to identifying an appropriate method of impact analysis is the available skill set of analysts within a region and existing economic models. If a country has the capacity to collect sufficient data or the skill set to construct a SAM and therefore a CGE or I-O model – which would be ideal for a single-event SDS – then a simpler method, such as surveys or a hybrid model, is required.

Another determining factor in the selection of an appropriate method for impact assessment is the budget available for the analysis. Undertaking a comprehensive survey of an economy is an expensive operation. The amount of data that can be collected using a survey or set of surveys may be a limiting factor.

6.7.2. Recommended approach

Given the diversity of resources to collect and analyse SDS economic impact data across countries, the recommendation here is that a relatively simple approach be taken. The preferred method is a hybrid of cost accounting and surveys, where surveys are used to identify costs that may not be readily available, such as household cleaning costs. Another reason for recommending this method is that it will allow cross-country comparisons, as all countries or regions will be using the same framework.

As noted throughout the preceding discussion, availability and consistency of data can be problematic when undertaking impact analysis, and also when comparing across events within a country or across countries. Another issue that arises with data-collection, and indeed impact assessment, is that of timescale and estimating the impact of multiple events from single-event data.

It is recommended that a consistent method of data-collection be utilized to ensure valid and relatively accurate data are collected. This will also allow valid comparison across countries or regions. A comprehensive set of guidelines for data-collection and data sources are provided in **chapter 6.13**.

One significant issue with respect to impact of SDS is related to the effects of SDS on human health and the attribution of an SDS event to mortality and morbidity in the impact region. It is recommended that research be undertaken to accurately measure the impact of SDS events on human health, and that this research properly identifies the true impact of SDS on human health. This implies that research must be comprehensive, beyond simple correlation analysis of hospital admissions and SDS events, that prior health status must be identified and that demographic variables such as gender, income, age, household location and construction must be fully captured in the data-collection and analysis.

6.8 Benefit-cost framework for analysing dust mitigation or prevention

6.8.1. Basic construct of cost-benefit analysis

Benefit-cost analysis (BCA) or cost-benefit analysis (CBA) is a method of analysis that is used to compare the investment value of different projects.[3] Cost-benefit analysis is a form of investment analysis that takes into account current and future costs and benefits associated with a project to estimate the net present value (NPV) of the project. Using NPV as a basis of comparison allows decision makers to evaluate projects that may have different income or cost flows throughout the life of a project.

An NPV model for a proposed dust-mitigation programme could take the following form:

$$NPV = -C_0 + \sum_{t=1}^{T} \frac{(R_t - C_t)}{(1+\rho)^t}$$

Where:

- C0 is the initial cost of the mitigation investment
- Rt and Ct are the revenues and costs generated from the mitigation programme
- t = 1 to T are the number of time periods in which the investment is measured.
- p is the discount rate and measures the time value of money

For example, NPV can be used to compare two projects:

- one with a high initial cost and a long period before income is received, such as planting a forest
- one with smoother income and cost flows, such as an annual cropping programme

The main difference between CBA and NPV investment analysis is that CBA extends NPV by adding non-market information to more extensively capture the true value or full costs and benefits of a project (Hanley and Spash, 1993). This extension allows policy and decision makers to understand the implications of including non-market information, such as the value that environmental or ecosystems services have, on a project’s total benefits and costs. One aspect that is not captured in CBA is the equality or distribution of wealth in different socioeconomic classes and how proposed investments affect these different groups (Wegner and Pascual, 2011).

CBA proceeds in a series of stages in a process which is fairly linear, although all stages may be overlapping in some sense.

3 A full description of the basics of ‘cost-benefit analysis’ and ‘net present value’ is beyond the scope of this chapter. Interested readers are referred to Harris (2006), Hanley and Spash (1993) or Robison and Barry (1996) as starting points for descriptions of the two methods.

Stage 1 is simply identification of the project, where:

- the first component is the resources that will be reallocated in the project – this includes financial and physical resources
- the second component is identification of the impacted populations, including both positive and negative impacts

Stage 2 is to identify the impacts of the project on reallocated resources. These impacts can be physical or financial – the reduction in dust emission and the costs of this reduction at the emission source, as well as the changes in the environmental services that occur because of the project.

Stage 3 involves identification of the economically relevant impacts. This may sound redundant, as most costs or benefits from a project will be economically relevant, but a major discussion in the economics literature concerns the inclusion of transfer or compensation payments. This will be discussed in more detail in a later section, but a brief précis on the context of SDS and compensation may be helpful.

For example, if a dust-mitigation project generates a net-positive benefit across a region, this indicates that the project is feasible, even if one of the impacted populations is negatively affected and another population is positively affected. The positively affected population could compensate the negatively affected population to balance impacts. However, in the context of CBA, this is considered a transfer payment and is not included in the "benefits" of the project.

Stage 4 is the physical quantification of impacts. This stage is critical, as quantifying the timing of these impacts is also measured. At this stage, if necessary, uncertainty can be included in the calculation of impacts, either physical or financial.

Stage 5 is the valuation of the impacts. At this stage, valuation includes taking into account the time value of money from Stage 4 when impacts occur. "Time value of money" takes into account the fact that, in theory, money loses value over time, so a dollar today is worth more than a dollar tomorrow. As a result, investors or project managers prefer higher returns earlier in a project than later.

6.8.2. Costs and timing of costs in cost-benefit analysis

Costs incurred and timing of costs depend on selected practice. For example, undertaking an annual cropping programme to provide some surface cover to reduce soil erosion will incur annual costs for seed, fertilizer, chemicals and pesticides (if used), some form of mechanization (machinery or draught animal) for ploughing, sowing and – if necessary – harvesting and labour required for all activities including sowing, harvesting, storage and transport. All these costs will be incurred each and every year of the farming programme.

If the preferred choice is to use some form of forestry for dust mitigation, a large investment is required in the first year for land preparation and tree planting. A lower cost may be incurred in the year immediately after planting the trees for activities such as weed control or irrigation of the young trees to ensure their survival. In subsequent years, very few costs will be incurred, as the trees require little maintenance, assuming long-term irrigation is not necessary. The level of maintenance costs incurred will depend on whether the forest project is a permanent forest or a harvested forest.

If the forest is to be permanent (not harvested), little maintenance is needed beyond the initial year or two. If the forest is to be harvested and replanted, then regular maintenance will be required for activities such as trimming and thinning to ensure a profitable crop can be harvested.

6.8.3. Discounting and the discount rate

When analysing investments over time, it is necessary to convert future costs and/or benefits to current values so that comparison of investments is undertaken in a standard value. To undertake the conversion, future costs or benefits are "discounted" by the discount rate, $\rho\,(0 \le \rho \le 1)$.

The discount rate is a measure of the time value of money. Higher discount rates imply that the time value of money is high, so income is preferred earlier rather than later in the life of an investment. A discount rate of zero implies that there is no time preference for income.

Selection of the discount rate depends on the risks involved, the current inflation rate, cost of money (the interest rate), and whether there is an additional consideration of the social rate of time preference (Harris, 2006). The selection of an appropriate discount rate for analysing a mitigation project is a critical decision and should not be made lightly. Selecting an inappropriate discount rate for project comparison can make a project appear to be more or less preferable, as the discount rate affects the current value of costs and benefits over the life of a project, and the current values change with different discount rates.

6.8.4. On-site benefits of dust mitigation at the source

On-site benefits can come from several sources. The first is relatively simple – the crop or timber can generate income, if that is the practice selected. However, timing of the income will differ depending on the practice chosen.

For an annual cropping programme, income will be received every year, where income will be a function of price and yield. For a forest, the majority of income will be received when the forest is harvested, with potentially some income in years when the forest is thinned.

The second source of benefit is through costs saved in the cropping programme through reduced soil erosion that can maintain or even increase crop yields, and loss of soil nutrients through dust emission to the atmosphere. In some cases, there may appear to be no obvious on-site benefits, but there may be some less obvious benefits. For example, a sand dune stabilization project may appear to have no on-site benefits, but if the stabilization project reduces dune encroachment on a road, then there is an on-site benefit.

6.8.5. Off-site benefits of dust mitigation at the source

Off-site benefits of dust mitigation are numerous, with the benefits contingent on the impact region, economic and environmental infrastructure and activity within that region, and the level and type of dust mitigation achieved in the source region. As discussed in earlier chapters, SDS affects many sectors of the impact region, thus any reduction in either frequency or severity of SDS or the amount of dust deposited during SDS may be beneficial. However, measuring the benefits can be difficult. Unless SDS are completely eliminated, there will still be some negative effects on the impact region.

6.8.6. Off-site benefits of dust mitigation in the impact region

Different types of mitigation processes can be undertaken in the impact region to reduce the effects of SDS. These include early warning systems or mechanical aids such as air filtration systems or improved building construction to reduce dust entering buildings.

Again, it may be difficult to measure impact, as only those segments of the population that are affected by SDS may take advantage of the early warning system or improve the construction of their home so as to reduce the impact of dust on their family. However, there is some indication that early warning systems for vulnerable segments of the population can reduce the effects of SDS.

Tozer and Leys (2013) report that during the Red Dawn event in 2009, affecting Sydney and other parts of eastern Australia, there was no significant increase in hospital admissions. They attributed this to a health warning system that sent SMS messages to those in the population with respiratory problems who had subscribed to the system. One point to remember here is that mitigation programmes or early warning systems in the impact region do not reduce the amount of dust impacting the region, they simply reduce the impact of dust on the region.

6.9 Non-market valuation methods for inclusion in cost-benefit analysis

The major challenge in CBA is estimating costs and/or benefits for attributes that may be impacted by SDS but have no identifiable market value or method to value them using market-based techniques, such as environmental benefits or ecosystem services. There are two classes of non-market valuation techniques: (i) revealed preferences and (ii) stated preferences.

- **Revealed preferences**, as the name implies, are modelled on actual behaviour, typically purchase or demand behaviour, that is, how and on what consumers spend their money (Just, Hueth and Schmitz, 2004).
- **Stated preferences** are based on what consumers say they are going to do, usually shown by survey responses (ibid.).

Within these two classes are different methods for revealed preferences. There is hedonic pricing and the travel cost method, and for stated preferences, contingent valuation and choice modelling.

A final category of valuation is to use some form of experimental analysis to identify the "value" for the "service" provided. Each of these different methods can be applied to various non-market issues arising in CBA of SDS mitigation strategies.
The literature on valuing ecosystem services – or for other system attributes which have no discernible market – is vast and comprehensive. See, for example, Ninan (2014) and the references and examples contained therein. From the perspective of CBA, the following techniques are presented as potential methods of valuation. As a full explanation of the techniques is beyond the scope of this chapter, readers are directed to the references section as a starting point for further information on methods discussed herein.

6.9.1. Hedonic pricing

Hedonic price analysis treats a "product" not as a single product but as a collection of attributes, qualities and characteristics which consumers desire and for which they are willing to pay. The price a consumer pays for a product reflects how they "value" each attribute of that product (Costanigro and McCluskey, 2011).

When a consumer purchases a car, they are purchasing the set of attributes contained within the car – safety features, colour, engine capacity, number of seats, brand and reputation, among other attributes. Some car brands are more expensive, such as Lamborghini®, and some are relatively inexpensive, such as Nissan®.

Consumers will pay more for the Lamborghini® because they are willing to pay more for the set of attributes associated with that brand rather than the Nissan®, even if the primary rationale for a car as a means of transport is the same for both brands. The application of hedonic pricing in CBA of SDS is relatively limited as there are few "products" involved in SDS mitigation that could be analysed in this way.

6.9.2. Travel cost method

The travel cost method uses consumer behaviour to measure the value consumers place on “goods” such as environmentally or culturally significant sites (Hanley and Spash, 1993). The method measures how much consumers are willing to pay to “travel” to a site, where paying includes travel costs, such as flying or driving, entry fees, accommodation costs, capital equipment (for example, camping gear), and on-site expenses such as food and drink. By summing the travel costs across the expected number of visitors to a site, the “value” of the site can be estimated.

6.9.3. Contingent valuation method

The contingent valuation method (CVM) uses surveys of consumers, usually in some form of controlled experiment. They are asked how much they would be willing to pay for a particular product or service with specific attributes. In ecosystem or environmental analysis, “consumers” are asked how much they would be willing to pay for the services provided by the ecosystem or environmentally sensitive area, or alternatively, they are asked how much they would be willing to accept for the loss of the services provided (Ninan, 2014).

6.9.4. Choice modelling

Choice modelling is similar to CVM, except that instead of valuing the service provided by the ecosystem or environmentally sensitive area, “consumers” are asked to value the specific environmental attributes of the area, then to choose between the alternatives that provide varying levels of the attributes (Ninan, 2014).

6.9.5. Experimental analysis

This method is used to address some of the shortcomings of the stated preference methods, such as the differences between what people say in the surveys, to determine willingness to pay and their actual behaviour, referred to as the “hypothetical bias”. In some experimental analyses, consumers use real money to determine a more accurate WTP. This can remove some of the hypothetical bias that may be apparent in survey responses in which there are no consequences for decisions made.

6.10 Examples of cost-benefit analysis for dust prevention or mitigation

There are numerous examples of SDS mitigation practices or restoration projects which are intended to address anthropogenic causes of SDS. The following are examples to demonstrate the application of CBA in measuring the costs, benefits, timing and location (on-site or off-site) of these costs or benefits, and other implications of the mitigation practice. The examples do not provide a comprehensive set of potential solutions.

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Any mitigation or restoration project needs to take into account local conditions such as soil type, water availability, aspect or topography on which to base the project design and the CBA process.

The four different scenarios are:

1. Land/soil surface mitigation through planting crops, re-establishing pasture or creating new pasture
2. Reforestation, including planning perennial tree crop
3. Off-site mitigation in the impact region.
4. Doing nothing

Note that “doing nothing” provides a comparison against the other three measures listed.

Each scenario will have a unique set of incomes and costs throughout the life of the project, which will affect the NPV of the project. Each scenario will also have different sets of non-market issues and income distributions.

One point to note here is that some of the following practices could generate benefits through carbon sequestration. However, due to a lack of well-established markets, these benefits may not currently be able to be measured, although they can be considered when markets are more established.

6.10.1. Land/soil surface mitigation

Pasture – No livestock grazing

If pasture or grasses are sown and **no** livestock are to be grazed then the on-site costs will be for the pasture seed and fertilizer, and any associated machinery or labour costs. The total costs of the pasture sowing project will depend on the area sown but will typically be incurred in the first year of the project, then some maintenance applications of fertilizer may be necessary in later years, and possibly permanent fencing to keep grazing animals out, if desired. There will be no on-site benefits except for the reduction in soil erosion over time.

Off-site benefits, which include the reduction of costs due to SDS, will depend on the area sown and the reduction in dust emissions from the source area (we also assume that there are no other mitigation practices undertaken in the impact region, thus there are no additional costs incurred in the impact region). One point to consider is that the full potential for reduction in dust emission may not occur in the first year of pasture development, as the pasture may take some time to establish and cover all exposed soil surfaces.

Pasture – Livestock grazing

The second option to allow grazing of the pasture once established. This will have a benefit in the source region, with income being generated by herders that use the land. If the “right” mix of pasture species is sown, soil erosion may be reduced and, in some cases, reversed. Similar to the “no grazing” approach, the benefits or reduced costs will depend on reduction in the amount of dust emitted from the source region.

In this scenario, pasture costs will be incurred in the initial year, and costs to purchase livestock – if not already owned – will also be incurred. Pasture maintenance and animal-related costs will be incurred in all years subsequent to the establishment year. Benefits will occur in each year that SDS impacts are reduced.

Annual cropping

An annual rain-fed planning system of one or several crops to provide soil surface cover or reduce the amount of soil lost through wind erosion can increase incomes in the source region and reduce costs in the impact region. In this scenario, the on-site costs may include crop seed and fertilizers, herbicides or pesticides, if needed, as well as labour (for sowing, crop maintenance and harvesting), machinery costs (if machinery is used) and costs of transport for taking a crop to market.

Assuming some or all of the crop is marketed, crop producers in the source region will benefit from the income. Both costs and income will be incurred and received in every year of the project. Similar to the pasture systems, benefits in the impact region will be due to the reduction in dust affecting the impact region. This reduction will be dependent on the amount of dust mitigated.

6.10.2. Reforestation

Non-harvested permanent forest

An alternative to annual cropping or animal enterprises is to establish some form of perennial crop, such as an agroforestry activity, or a perennial tree crop, such as an orchard or other plantation-type operation. The costs and benefits in these types of enterprises are very different to annual systems, in that a high establishment cost is incurred in the first year of the project, with no or very limited income in early years, while the perennials become established.

For a non-harvested forest, a very large investment cost is incurred in the first year of the project with the purchase and planting of trees, land preparation, and, if necessary, irrigation or some other form of water application system to ensure trees will grow. One significant cost in this operation will be labour for land preparation, tree planting and forest maintenance. Some costs will also be incurred in the years immediately after establishment to ensure the forest grows as desired and trees grow towards maturity. Given that the forest is not to be harvested, there will be no income derived from the forest itself, but other income may be generated if the forest is open to recreational activities, such as camping, hunting, walking, or harvesting mushrooms or wild plants.

The dust mitigation benefits of this type of practice will vary over the period until the forest becomes fully established. In the early years of the forest, dust mitigation may be relatively low as the trees will not provide sufficient wind speed reduction to significantly lower dust emission. As the forest matures, the reduction in wind speed will reduce erosion and subsequently reduce dust, which may be deposited in the impact region. In other words, the off-site benefits will be low in early years then steadily improve until the forest reaches maturity. Again, the scale of benefits will be contingent on the level of dust reduction due to the forest.

Commercial harvested forest

The initial costs of a commercially harvested forest will be similar to the non-harvested forest, as land needs to be prepared and trees planted. However, more costs will be incurred in subsequent years, as forest maintenance is required to ensure the harvested lumber generates higher income.

The other main difference is that income will be generated when the forest is harvested, and there is also potential for a small income to be generated from either sales of trees thinned to ensure high quality trees will be harvested at the end of the forest's lifespan or from charging for access to the forest to harvest wild plants. For the forest to continue providing a dust mitigation benefit, land preparation after the forest is harvested needs to incorporate dust-reduction measures and the associated costs.

The dust mitigation benefits in the impact region will also be slightly different than for the permanent forest. There may be periods during the forest establishment period when mitigation benefits are reduced while the new forest grows to a size in which dust emission reductions can be observed in the impact region. However, as with all dust mitigation strategies, the level of dust reduction in the impact region will depend on the scale of the forest project.

Commercial perennial fruit or nut orchards

In this scenario, the orchard is a commercial operation producing fruit or nuts. A higher initial cost would be expected as more infrastructure, such as a more extensive irrigation system, may be required, and fruit trees would be expected to be more expensive than forest species.

Depending on the fruit, nut or mix of fruit and nut trees, the income flow will vary somewhat, but it would be expected that the orchard would begin to provide economic levels of production within three to four years of establishment. This income would grow until the trees reach a mature size and steady production level by about year six or seven after planting. The cost structure for an orchard will also be different, as costs will be incurred in all years after establishment, even in years when the trees are not producing a crop, as they still need care and maintenance to ensure maximum possible crop production when they do mature.

An orchard will mitigate dust through reduced wind speed and soil erosion. However, similar to the forest options, the level of mitigation will be low in the years before the orchard reaches maturity. Again, the level of dust mitigation in the impact region will depend on how much dust emission reduction occurs in the source area due to the orchard.

One point to consider here is that it is possible to combine any of the options listed above to reduce dust emission from the source region. This may be a preferable option in regions where livestock raising is a main source of income, as trees, in the form of wind breaks or small forests, can be used to reduce wind speed across the soil surface and allow the establishment of pastures or annual crops. If developed with appropriate tree species, forests can also provide wood for fuel and dust mitigation if the trees can be coppiced for wood supply. Also, forests or crops can provide non-timber or non-food products such as medicinal products or raw material for further processing, such as tree saps.

6.10.3. Off-site mitigation

Governments, occupants or businesses in the impact region of SDS can undertake practices to reduce the impact of sand or dust on their region, lives or businesses. However, the key point here is that any practice will not reduce the level of dust deposited in the region, as the dust originates at the point of origin. Examples of dust mitigation practices include early warning systems. Warnings enable vulnerable segments of the population and important sectors of the economy to take action to reduce the impact of SDS on that segment or sector. In anticipation of warnings, building improvements, such as air filtration systems or installing tighter fitting windows and doors, can be used to reduce dust penetration into buildings or houses.

Early warning systems, in some form, can reduce the impact on important sectors. For example, in the transport sector, airlines can initiate programmes to reschedule or cancel flights before passengers arrive at the airport to board their aeroplane, thus reducing the costs of cancellation or incurring accommodation and other costs due to flight cancellation. Similarly, for road transportation, early warnings can be provided to those people planning on driving, and this may reduce road accidents due to the poor visibility caused by dust. These warning systems ensure that vulnerable segments of the population – such as those with respiratory or cardiovascular problems – remain indoors or in locations where dust levels in the air are relatively lower to reduce the probability of more serious health issues arising.

Construction or modification of buildings to reduce dust penetration is an option that has been used successfully in some regions of the world to reduce the impact of dust on processes or people. For example, Samsung® in South Korea modified their buildings' housing manufacturing processes to reduce the number of faults in components manufactured during SDS events (Kim, 2009).

The costs of the mitigation process will depend on the type of process. In the

case of early warning systems, it would be expected that governments would bear most of the cost, and the costs would depend on the type of system designed and implemented and the types of warnings given to the population. When individuals or firms choose to construct or modify buildings, then it would be expected that individuals or firms would be responsible for the costs.
As for the benefits of these practices, these would depend on the reduction in problems caused, such as reduced mortality and/or morbidity, road accidents or flight cancellations. Through reduced costs, the benefits could also flow to private corporations, such as airlines, as the costs of flight cancellations or aeroplane repositioning may be reduced, due to the early warning systems developed and implemented. As noted above, the benefits of these types of approaches will be to the segments of the economy mostly at risk. There may be no reduction in other areas, such as road cleaning, due to there being no reduction in dust emission from the source area.

6.10.4. Doing nothing

While this may seem a trivial option, it is still an option in some regions or countries, simply because they may not perceive any benefits from incurring costs to reduce SDS, or they may think that the costs of reducing SDS far outweigh the benefits. Another issue that arises here – and which will be discussed in more detail in a later section – is that of transboundary issues, with respect to the distances dust travels from source region to impact region.

In the above discussion, most mitigation projects were in the context of anthropogenic sources of dust and can include water management projects. However, they may also include natural sources of dust that may be causing significant off-site costs, although these types of projects would need to consider natural cycles and what the implications would be if the source was mitigated.

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6.11 Issues in cost-basis analysis

There are several issues within the context of dust emission and mitigation practices that also need to be addressed in a broader context than the confines of the practices discussed in **chapter 6.10**. These include the:

- distributional effects of costs and benefits and the distribution efficiency of wealth and income of the proposed practices
- transboundary issues, particularly with respect to costs, benefits and potential compensation in the source and impact countries or regions
- land tenure issues, with respect to land being accessed or used in mitigation practices

6.11.1. Distributional efficiency

When analysing the results of a CBA for a proposed mitigation strategy, the benefits may outweigh the costs. Therefore, the strategy – from a purely economic perspective – is worthwhile (as the project is allocatively efficient). However, from a wealth distribution efficiency perspective, this may not be the case. For example, if the practice requires that previous users of the land be displaced, and their sources of income or wealth are reduced, then they may suffer losses of either income or wealth.

Even if there are sufficient excess benefits to compensate for this loss in the project, there may be no compensation forthcoming from within the project. This argument also holds if the "wealth" of the society is increased by the project, yet more landholders who are displaced have their wealth reduced after the project than those in the impact region who may have their wealth increased due to the project, resulting in a redistribution of wealth to the detriment of those in the source region.

6.11.2. Land tenure issues

One important factor contributing to the success or failure of a mitigation project relates to land tenure, and this is also related to the previous point regarding wealth distribution. Land tenure is important, as it has implications for the incentives to be provided to landowners to undertake any dust mitigation project proposed. For example, if a project requires that land be taken out of some form of production for a number of years, and that land is privately owned, then the landowner would need to be compensated in some form for the loss in income.

One type of land ownership that could create some issues in terms of desertification and dust mitigation is that of "commons", or common property, where land may be owned by government but access is unrestricted. Commons and access to commons can lead to the problem identified as "the tragedy of the commons" (Hardin, 1968).

In this research, Hardin (1968) discusses the implications for unlimited or unrestricted access to common property using a grazing common as an example. Without restricting access to the common, individuals will graze their own livestock without consideration of the behaviour of others, which in turn leads to overgrazing and degradation of the commons, which in the long run has a detrimental effect on everyone.

In terms of desertification and dust mitigation, commons may be a source area of dust emission due to overgrazing or the removal of tree cover for wood for fuel. Reducing access to users of the land may lead to reduced income or reduced wealth, as farmers may have to reduce stock numbers due to limited access to grazing.

In terms of dust mitigation projects, if part of the commons is to be utilized in a dust mitigation project, the question then arises as to what happens to those who were accessing the commons. Will they be compensated? If the area of the commons is reduced, will access also be reduced to ensure overuse does not occur?

Using a simple example may help in understanding the problem. Assume there is a commons of 1,000 hectares and that 1,000 sheep – owned by many farmers – graze on the commons, therefore the stocking rate is one sheep per hectare. If a dust mitigation project reduces the commons area to, say, 900 hectares, there are one of two potential outcomes for the farmers grazing their sheep on the commons: (i) the same number of sheep graze the reduced area, increasing the stocking rate to 1.1 sheep per hectare or (ii) the number of sheep is reduced to 900, to maintain the stocking rate at one sheep per hectare.

The questions that arise here are:

- How do policymakers reduce the number of sheep by 100?
- How do they do that equitably?
- Do policymakers then allow the extra stocking rate and potential overgrazing in the commons?

6.11.3. Transboundary issues – costs, benefits and/or compensation

As noted earlier, transboundary issues are a common problem with SDS events, as dust can travel vast distances, crossing many national borders from the source to the final deposition region. Addressing or considering transboundary concerns in determining both the impact of SDS to begin with – and what the process may be for determining the process to be employed in developing and implementing dust mitigation strategies – is critical to the success of any mitigation practice.

For example, if dust is emitted from one region, without affecting that region except through the loss of soil and soil nutrients (as discussed earlier), then that region may not be willing to undertake mitigation, due to the costs of the proposed work, with potentially little benefit to that region. However, the countries in the impact region may offer to fund dust mitigation programmes, as there is a benefit to the countries providing the funds through a reduction of the cost of dust impacts.

One important issue with respect to transboundary issues is that of national sovereignty and how costs, benefits and compensation may affect sovereignty. For example, one nation that may be affected by dust may offer to help pay for dust mitigation in another, with the aim to reduce the effects of dust on the population of the donor country. This may need to be done in a manner which achieves the desired goal for the donor country but does not impinge on the recipient country's sovereignty. These types of issues could be addressed with tools such as debt-for-nature swaps (United Nations, 1997), whereby a country (or countries) in the impact region could reduce a source country's debt in exchange for that country undertaking a sand or dust mitigation strategy to reduce emissions.

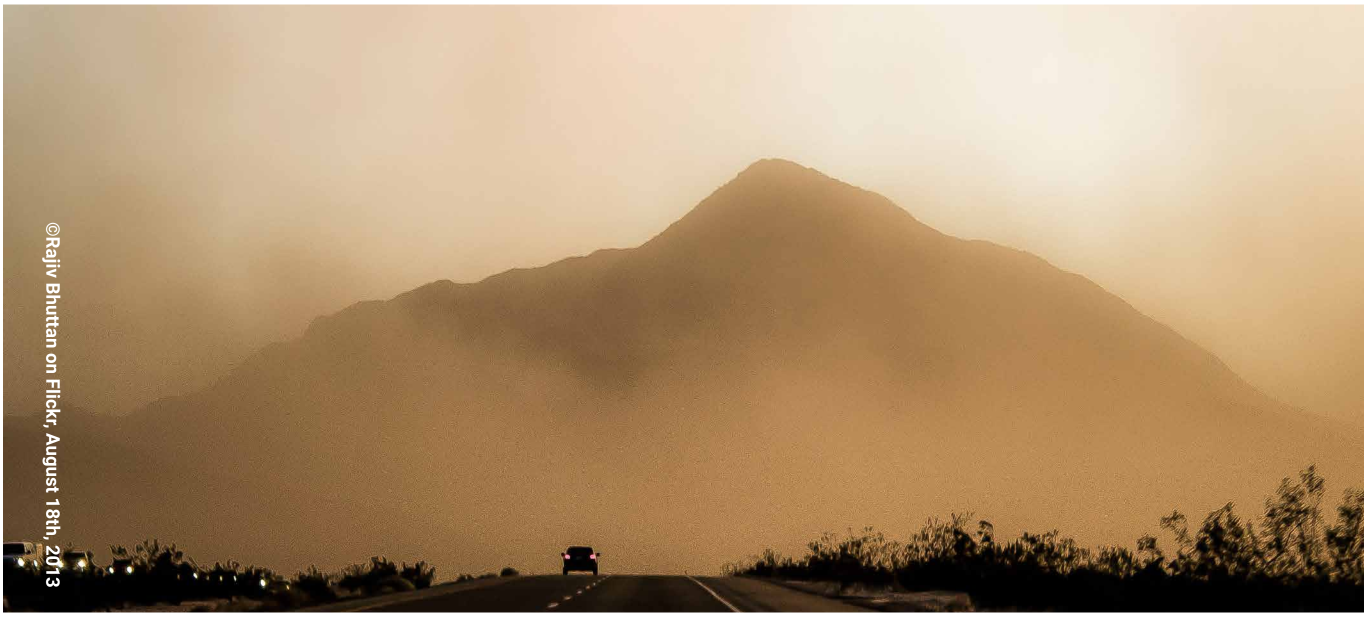
6.12 Conclusions on cost-benefit analysis

The basis of CBA for measuring dust mitigation projects is relatively straightforward. However, there are several issues that need some structure. The most significant of these is non-market valuation – and selecting the most appropriate method of non-market valuation to measure costs and/or benefits in dust mitigation projects. In the case of the different costs and benefits of a mitigation project, there will more than likely be one more appropriate method of non-market valuation, but the most appropriate method will vary with the type of non-market problem being measured.

For example, ecosystem services can be measured using different methods, such as the travel cost or contingent valuation methods. The selection of method is somewhat determined by the main "user" of the ecosystem service. Thus, there is no definitive recommendation as to the "most appropriate" method of measuring non-market valuations across all types of costs and benefits, but researchers are encouraged to consult the extensive literature on non-market valuation techniques applicable to the type of cost or benefit being measured.

Also, as noted above, the selection of an appropriate discount rate is critical to measuring the net value of any mitigation project. The key recommendation here is that the discount rate should include investment costs and societal values – attached aspects of the mitigation projects. This is particularly important when measuring the costs and benefits of projects that impact or are impacted by non-market factors, such as ecosystem services or cultural locations.

The other main issue with respect to CBA is that of compensation and distributional efficiency. However, again, there is no definitive recommendation, as most of these issues are dependent on the affected population and on country policies. It would be preferable for distributional efficiency be taken into account when determining compensation or other effects of dust mitigation projects on the populations of the source or impact regions. Recommendations on transboundary costs, benefits and compensation are also not made due to factors such as national sovereignty and determination of appropriate methods for estimating costs or payments in dust mitigation projects.



Box 12. Integrating gender into the cost-benefit analysis process

Gender considerations: A cost-benefit analysis can disaggregate costs and benefits according to different groups, including men, women, youth and people with disabilities, to better understand who incurs the costs and who enjoys the benefits from specific measures. A good gender analysis that identifies expected costs and benefits to men and women is a prerequisite for being able to value them on a disaggregated basis.

Why do it?

A cost-benefit analysis can help inform decisions about whether to proceed with an activity, decision or project and/or choose which option to implement. It can be particularly valuable for advocacy and communication to involve decision makers in finance and planning to demonstrate the expected social and economic returns associated with a project (i.e. for every $1 invested, how much society will benefit). A good cost-benefit analysis can expose the real (and sometimes hidden) costs facing women (for example, in terms of time spent working), and by demonstrating the economic return on these initiatives to society, support arguments for investing in capacity-building and support to women. Consideration of distributional issues within a cost-benefit analysis framework is also vital in terms of assessing the feasibility of options. If one particular group is disadvantaged by a proposed option, they are unlikely to support the initiative, which will undermine the achievement of results. Consideration of distributional issues therefore provides invaluable information on how project design should be adjusted to account for these factors.

When to do it?

A cost-benefit analysis can be used at various stages during the programme or project cycle:

- During the solution analysis and design phases, it can help inform the design of the project proposal and appraise the worth and feasibility (or otherwise) of the proposal(s).
- During implementation, it can check that the project is on track and inform any project design refinements and adjustments for the remainder of the project period.
- As part of an evaluation at the end of the project period, it can evaluate its performance or success. This can support transparency and accountability in reporting on how well funds have been spent and learning about whether a project (or that type of project) is worthwhile and should be replicated.

Entry points for gender analysis

At the heart of the consideration of gender within a cost-benefit analysis framework is the treatment of equity and distributional impacts. The basic measure of overall benefits in a cost-benefit analysis reflects economic efficiency: $10 of benefits accruing to a poor farmer are treated the same as $10 of benefits to a wealthy hotel owner. In reality, societies commonly give greater weight to gains by disadvantaged groups. Consideration of how gains and losses are distributed is vital to ensuring that social equity is considered alongside economic efficiency.

In a cost-benefit analysis, the value of costs and benefits is determined by people's willingness to pay for (or how much they would pay to avoid) a good or service.

In reality, the willingness to pay is affected by the ability to pay. This means that the valuation of costs and benefits is based on the current ability of society to pay, or in other words, the current distribution of wealth in society, including existing inequalities in that wealth distribution.

A cost-benefit analysis is one tool that can feed into the decision-making process. Its results should be considered alongside other tools that examine equity and distributional issues in more detail.

Steps to incorporate gender into the cost-benefit analysis process

1. Determine the objectives of the cost-benefit analysis

Ensure that all relevant stakeholders (including men, women, elders, youth, children and people with disabilities) have fed into the decision-making process on which options to assess. Whose priorities are represented?

2. Identify costs and benefits – with and without analysis

When identifying the different costs and benefits and based on a good understanding of the underlying situation and problems, ensure that information on the distribution of those costs and benefits is captured and documented.

3. Measure, value and aggregate costs and benefits

When measuring, valuing and aggregating costs and benefits, ensure that no detail relating to the distribution of costs and benefits is lost.

4. Conduct sensitivity analysis

A sensitivity analysis tests the results of a cost-benefit analysis for changes in key parameters about which we are uncertain (for example, rainfall). If a sensitivity analysis alters the distribution of costs and benefits significantly, ensure that this information is captured.

5. Consider equity and distributional implications

This section should expose any equity or distributional issues related to the costs and benefits of different options and how they might affect the feasibility of the project. Possible approaches for maximizing benefits accruing to particular groups, including women, and measures for addressing any groups that are disadvantaged by the proposed options should be discussed.

Adapted from Vunisea, Aliti and others (2015). The Pacific gender & climate change toolkit. Secretariat of the Pacific Community. Available at https://www.pacificclimatechange.net/document/pacific-gender-climate-change-toolkit-complete-toolkit. Accessed on 17 July 2019.

6.13 Data-collection for assessing the economic impact of SDS

6.13.1. The need for good data

Good data are the key to assessing the economic impact of SDS. This data needs to include gender, age and health status of the individuals covered in any assessment.

The challenge for gathering good data is that some of the impacts of SDS are difficult to measure directly, such as household cleaning or impacts of mortality and morbidity in the population. Another challenge that arises is that of duration and frequency of SDS events, which makes estimating costs more difficult, as some costs are ongoing, and it is sometimes hard to clearly define costs incurred for each event. There are numerous sectors impacted by SDS events and the timing of some events can be especially costly, such as an event that occurs during flowering of a perennial tree crop or annual crop, reducing fruit set or total yield of a crop.

One of the challenges for data-collection for the purpose of measuring the impact of SDS is the timescale of data measurement. For example, given the infrequency of major dust storms in Australia, Tozer and Leys (2013) reported the impacts of a single major dust storm. However, as noted above, SDS events in other regions of the world occur on a more frequent basis, thus possibly making data-collection more difficult.

The other challenge for measuring impact is the determination of the effect of frequency of SDS in any one year on the overall economic impact. For example, data collected for one year in which there were few SDS events may underestimate the average economic impact across time and overestimate the impact if the data are collected in a year in which there were more frequent events. Thus, the challenge of scaling up or down due to timescale and frequency of events needs to be considered when analysing data to measure the economic impact of SDS. The number of sectors impacted by SDS throughout a year will depend on the major economic sectors in each country, where and when SDS events occur, and the geography and location of major infrastructure throughout a country. For example, a landlocked country will not have a port sector, thus, sea transportation will not be affected. Also, many countries that have major industries – such as oil and gas exploration and extraction or electronics manufacturing – could face significant costs of SDS if these industries have to cease production due to SDS events.

6.13.2. Types of data required for each sector

Agriculture

Annual crops – Crop losses due to sand or wind blasting can be a complete loss of crops in a particular region or a reduction in yield due to partial losses. To measure these types of impacts, ascertaining areas of all crops – or the most significant crops – in a region or country is necessary. Also necessary is a method to compare yield losses in the cases where yield was affected.

Perennial crops – Similar to annual crops, but there may also be a longer-run effect on some perennial crops if trees or plants, such as Lucerne/alfalfa crowns, are damaged.

Animal production – This can be affected in several ways. If the system is using animals for milk production, there may be a reduction in milk produced during the SDS event, thus costing the producer income with no compensatory reduction in costs.

The SDS event may lead to the loss, either through death or animals fleeing the SDS and the producer not being able to locate them afterwards, so there may be a loss in terms of a reduced number of animals. The final loss for animal producers would be through lost, destroyed or damaged feed stocks, either pasture or forage crops. Measuring these types of variables will be difficult, but if we can capture animal losses, that will at least be a start.

Transport

The transport sector is one of the economic sectors most affected by an SDS event and depending on the transport infrastructure in a country, the costs can be substantial.

Air – The airline industry is most affected due to airport closures leading to cancellation, delay or diversion of aircrafts. This translates into costs for airlines and passengers. The minimum data needed for this are the number of aircrafts delayed, diverted or cancelled at each location. These may be sourced from the national department that handles air traffic or from the airlines themselves. If possible, the number of passengers affected would be really useful, and if possible – but highly unlikely – the costs incurred by the airlines due to the SDS event(s). Also, if possible, the costs of cleaning airport facilities, especially runways and taxiways, would be useful data. One good source of data for estimating the cost of aircraft delay is Cook and Tanner (2011). This research is focused on air traffic control delays but contains numerous estimations of costs for aircraft delay and for passenger and crew costs.

Sea/water – The impacts and costs in this sector will be due to different factors, depending on the aspect considered. For port operations, such as loading and unloading of ships, there could be delays caused by the SDS event(s), and in this case it will be necessary to know, if possible, what the costs of delayed loading/unloading are. For ferry operations, it is necessary to know the number of ferries delayed or cancelled and the number of travellers affected. If possible, finding out how travellers pay for their ferry fare would be useful.

Land – The costs incurred in the land transport sector are due to three separate impacts: road closures, road cleaning and road accidents. Road closures and traffic reduction data may be sourced from the department responsible for road or transport. The impact of closures and similar impacts will usually be relatively small unless a major highway is closed for a significant amount of time.

Road cleaning costs will depend on whether this is undertaken and where road closures are the source of data, the case may be the same.

Traffic accident data are necessary to estimate the costs of injury or death due to accidents. However, it is important to make sure that the accidents occurred during a period of SDS or as a result of low visibility caused by SDS. The source of data for traffic accidents may be the emergency services that attend accidents, or a transport-related agency that collects data on these types of events.

Another cost incurred by the transport sector is reduced income due to loss of business on the day(s) of an SDS event. Some measure of reduced income or number of loads carried would be useful. Again, this may come from a government agency, or even a private transport agency that represents the transport industry, as they may collect data on this.

Infrastructure

Infrastructural impacts of SDS are usually on the physical aspects of the infrastructure, either damage or cleaning of infrastructure. Sometimes, there is no damage or cleaning, depending on the severity of the SDS event. Also, some types of damage cannot be measured and therefore cannot be costed. This is particularly the case with siltation of waterways or dams.

Electricity – The main costs here are damage to pylons or transmission lines, and the main consideration here is that the damage is due to SDS. In some cases, SDS may lead to damage, but there may already be pre-existing conditions that contributed to the final damage caused by SDS. Cleaning of transmission lines and/or insulators may also be undertaken to reduce the potential for electrical short circuits and fires. The costs of damage and/or cleaning could/should be available from the electrical transmission company. Also, in some countries or regions where electricity is generated by solar plants, the costs of cleaning of solar panels may be available from the plants or electricity generation company.

Water and gas

These utilities are not usually affected by SDS, as they are typically underground. However, if there are reports of damage, please gather any data you can.

Construction

The construction industry costs are due to delays in construction. Thus, we need to know how much construction activity is going on in an economy, and how the SDS event(s) impact construction activity, such as how many worksites were closed down and for how long.

Oil and mineral exploration and production

Similar to the construction industry, costs are due to delays in exploration. Therefore, we need to know how much exploration activity is going on in an economy, and how the SDS event(s) impact on exploration activity, such as how many worksites were closed down and for how long. A second impact on the oil and mineral extraction industries is reduced revenue when oil wells or mines are not operating. Therefore, we need to identify if these facilities are impacted by SDS. Some mines, such as underground mines, may be less affected than others, such as open-pit mines.

Commercial activity – Retail/wholesale

Commercial activity is probably the hardest sector to measure, as there are no observable impacts other than the possibility of fewer people purchasing goods. The best way to measure this is through survey data, but in most cases, this is not feasible. To measure the impact, we use a scale of sales activity based on national retail/wholesale sales data, which should be obtainable from one of the economic agencies within a country, such as the central bank or a department of treasury or finance.

Manufacturing

Manufacturing will only be impacted by SDS if the particulate matter enters the manufacturing facility, or if materials required for production are held up in transit, causing delays. For example, electronics component manufacturers in Korea noted that on days of high particulate matter, there were more faulty products or faults in final components. Collecting data on this will be difficult due to facility-specific issues, but may be possible through survey work at a later date, as shown by Kim (2009).

Emergency services

Calls and requests for emergency services, such as police, ambulance or fire, may increase during SDS due to health incidents, fire or road accidents that may be a result of the events. Data for this type of service can come directly from the police, fire or ambulance services, or indirectly through the agency that manages these services. To ensure that there is indeed an increase in service requirements, it is necessary to gather data from comparable periods with no SDS activity.

Health

The impacts on health can usually be measured in either admissions through accident and emergency rooms or some other proxy such as ambulance activity. The best source is through the health department or the agency that manages hospitals in the region impacted by the SDS. Again, it is necessary to have a comparative set of data for periods when there is no SDS activity.

Absenteeism

Absenteeism is the absence from work of employees due to family or caring responsibilities. Some costs of absenteeism are already captured in costs of production, but research has shown that there is a reduction in productivity as well as production. The problem with measuring absenteeism is putting a number on the percentage of people absent from work due to an SDS event, as well as ascertaining the typical absentee rate for a particular country or region with which to compare it.

Households

Many household costs are captured under other headings, such as absenteeism or health, but the major cost for households due to an SDS event is cleaning, which includes cars, internal and external cleaning, and repairs and maintenance of vehicles and structures if necessary. It may be possible to assign some value to these costs if, for example, we know the replacement rate for air conditioners and other types of filters, the duration of the SDS event and how much matter was deposited.

The other costs households incur are for dust mitigation. These can include investments in new doors and windows that seal out dust more effectively, or air-filtration or conditioning systems, so some measure of these would be helpful. However, identifying which investments were made for dust mitigation as opposed to lifestyle improvement may be problematic.

Arts, sports and leisure

Many events and activities in the arts, sports and leisure sector can be limited or cancelled due to health concerns or lack of attendees. Therefore, if it is possible to identify which events may be cancelled and the potential loss of income for this sector, many events that are cancelled are not replaced and ticket holders usually get their money back, again the loss in income is due to the costs incurred in organization and preparation.

Schools and education facilities

School and other education facilities may be closed due to an SDS event, but in many cases, there is no direct loss in income or increased costs, as teachers and other workers in this sector are paid regardless. The main cost in this sector would be parents and carers having to stay at home to care for children and other dependents, and these costs would be captured in the absenteeism chapter.

Concluding comments

In some cases, it may not be possible to directly obtain the data required, but other sources such as media reports, insurance companies or other similar agencies, as well as secondary data, can be used to validate and/or verify estimated or assumed values. In other cases, the sector is not a major sector in the region or country's economy, so it is not critical that the data be collected.

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6.14 Conclusions

This chapter covered an assessment framework for the economic impact of SDS. Different approaches have been discussed and the data requirements for these approaches presented. Types of costs, direct and indirect, market and non-market, and on-site and off-site, were defined. One key point here is the difference between value and cost, which is critical in estimating the economic impact of SDS. SDS impact many sectors of an economy. These sectors were identified and the types of impacts SDS may have on these sectors were discussed.

The challenge with any economic analysis, particularly for natural disasters, is that of data requirements and availability, and this will drive the "ideal" method of analysis. Input-output (I-O) modelling is difficult in the context of SDS, as I-O requires a base-year without SDS as the comparison year for measuring impact. Computable general equilibrium (CGE) models have been used to measure the impacts of natural disasters, but require significant amounts of data, and are reliant on parameters to measure economic impact. Surveys and accounting methods have also been used and do capture the impacts of SDS but require full identification of impacts and assumptions regarding costs and measurement of these costs.

The key aspect of the successful construction of an SDS economic impact assessment is the availability of good data, meaning data that accurately measures the impact of SDS events. Data-collection also needs to be comprehensive to cover all affected sectors of the economy.

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