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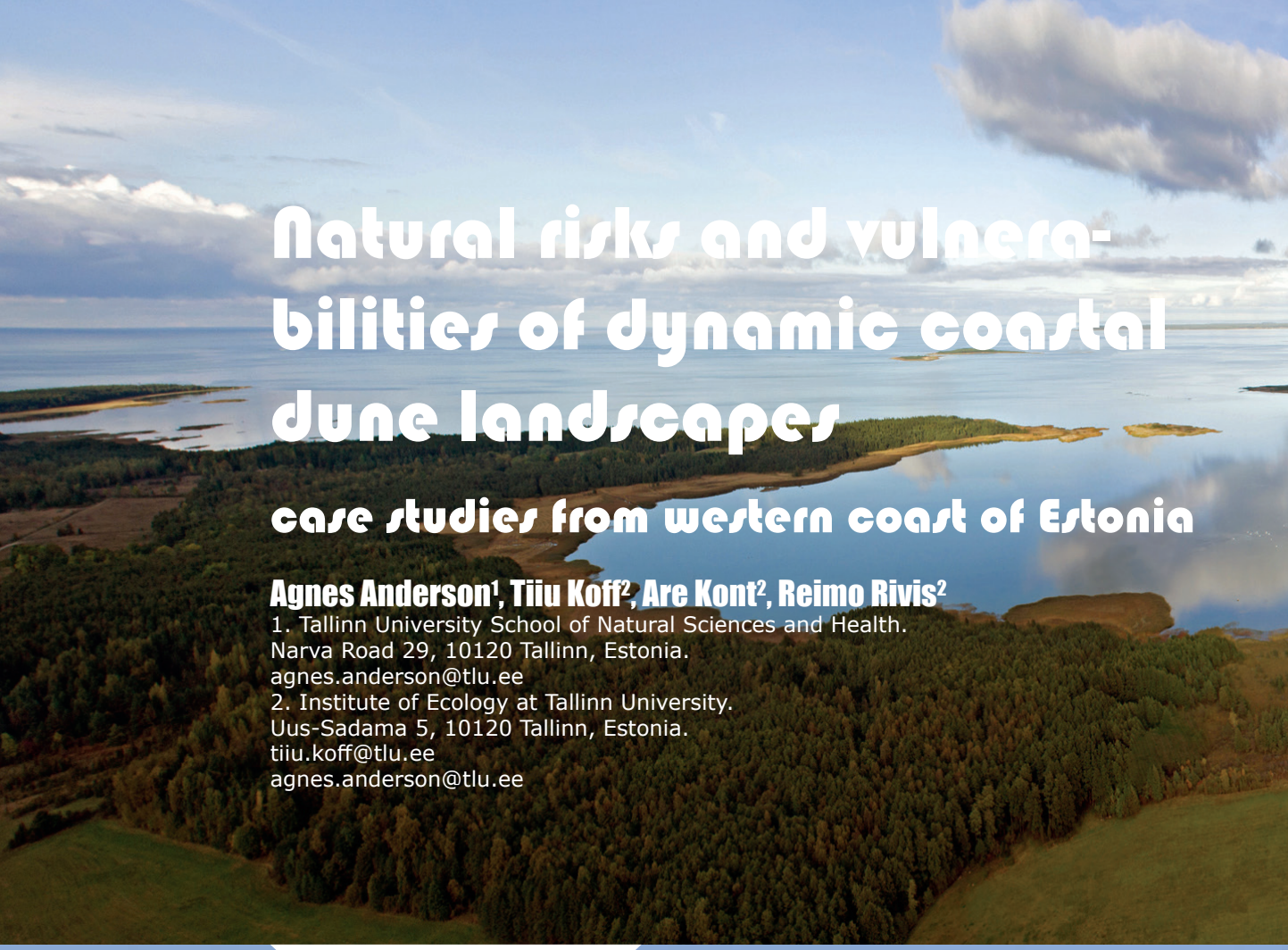

Natural risks and vulnerabilities of dynamic coastal dune landscapes

case studies from western coast of Estonia

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Abstract

Set in the Habitats Directive as priority habitat, fixed dunes with herbaceous vegetation (grey dunes) occur around the coasts of Europe. As a part of many coastal dune systems these habitats are especially complex and low resilience and need special attention from the conservation and management perspectives. Nearly a decade we have studied representative examples of fixed dunes in Estonia. Due to growing anthropogenic pressure and ongoing global changes it is vital to distinguish the changes and analyse general trends of development of grey dunes. The selected sites Keibu (located on the NW coast of mainland Estonia) and Ruhnu (located on the eastern coast of Ruhnu Island) are representative examples in Estonia, with a coverage of a geographical range and ecological variation. Both sites are part of conservation and monitoring areas. In each site, we have compiled a landscape profile to visualize the topography, vegetation and soils. he study was carried out on perpendicular to shoreline landscape profiles in order to express the full spectrum of coastal dune plant communities and surface deposits from shores towards inland. Both, natural and human impacts have been considered in the assessment of changes in the structure and functioning of the grey dunes in Estonia. The results show that changes in dune landscapes can be rapid, especially on sandy beaches

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Hellamaa Panorama (photo : Hiiumaamudeliklubi, 2013, wikimedia commons, CC BY-SA 3.0).

due to stronger storm surges in recent decades. The inland areas are more affected by human activity and the changes there are well reflected. The gradual loss of open sandy habitats on the sites is evident during the last 100 years and show the overall development trends of dynamic coastal dune landscapes. This study has proven that these areas need permanent observation to assess the level of changes. It is vital to contribute to the decision making processes concerning their optimal use and conservation needs to maintain their resilience.

Key words

grey dunes, sandy beaches, Habitats Directive, monitoring, conservation, management.

Introduction

Worldwide, coastal ecosystems are under increasing anthropogenic pressure due to real-estate development, tourism etc. Natural changes have played significant role, e.g. higher sea-level causing coastal erosion as well (Vestergaard, 1997; Carboni et al., 2009; Provoost et al., 2011; Ciccarelli et al., 2012). These ecosystems carry high value, especially for the society who receives

many benefits from recreation, conservation and aesthetic perspective. Unfortunately today`s economy favour over-exploitation of these areas, specially beaches and coastal dunes and the society is left to deal the outcome (Ciccarelli, 2014).

Coastal landscapes are engaging and dynamic, yet threatened ecosystems across Europe and elsewhere. Coastal dunes can act as natural protection against storm surges (Tõnisson et al., 2018). Since the inventory of sand dunes was published, a higher focus has been set to the sand dunes of Europe to improve their ecological diversity through conservation and management (Doody, 1991; 2005; Martínez et al., 2004). Habitats Directive was adopted on the conservation of natural habitats and species to ensure the long-term biodiversity of Europe's most valuable and threatened species and habitats. One of these habitats is grey dunes, distributed on the coasts of European countries, including France and Estonia (figure 1). Due to hazardous conditions (increased storminess, higher sea-levels, storm surges) it is vital to implement monitoring and provide understanding of these habitats (figure 2).

Figure 1. Distribution of the habitat type 2130 in Europe. Habitat marked in blue colour. Based on Natura 2000 Network Viewer. http://natura2000.eea.europa.eu/ (p. 70).

Figure 2. Main influences of Estonian coastal dune landscape and the main habitat types (1210 - annual vegetation of drift lines; 1640 - boreal sandy beaches with perennial vegetation; 2110 - embryonic shifting dunes; 2120 - white dunes; 2130 – grey dunes; 2140 - decalcified fixed dunes with Empetrum nigrum; 2180 - wooded dunes) (p. 71).

Grey dunes is a priority habitat type and needs recommendations for conservation and management. Therefore, their status is observed by the Estonian national environment monitoring programme and reported to the European Environment Agency. Initially, the National Environment Monitoring Programme (1996-2012) aimed to analyse landscape structures as a whole and no special attention was given to each habitat type because of the lack of favourable conservation status criterias (Development of relevant..., 2016). With new Environmental Monitoring Act, the purpose of monitoring is focussed on specific habitats by assessing and analysing their status besides changes in biodiversity, relationships with human activities and natural processes, impact of land use, monitoring landscape changes and forecasting possible trends. The monitoring results contribute to the decisions concerning their optimal use and conservation needs.

Grey dunes are characterised by undulating dune forms. In earlier stages of development grey dunes are herbaceous-rich. In later successional stage, they are characterised by perennial grasslands and in plenty of lichens and mosses. Vegetation development and soil formation processes often suffer from different environmental impacts, e.g. drought which is one of the most unfavourable factors (Provoost et al., 2004; Psuty, 2004; Wiedemann and Pickart, 2004; Isermann, 2005).

Estonia is located on the eastern coast of the Baltic Sea and the climate has more maritime influenced in the west than in the east. Estonia has encountered apparent climatic changes from previous decades until present. On the coast exposed to the west, the observable changes in climatic conditions are evident due to shifts in atmospheric circulation resulting in warmer winters, increase in strong westerly storms associated with high sea levels in ice-free sea conditions (Orviku et al., 2003; Jaagus, 2006; Kont et al., 2007, 2011; Orviku et al., 2009; Tõnisson et al., 2011; Palginõmm et al., 2018).

In Estonia, six major shore types can be distinguished - sandy, cliff, till, silty, gravel-pebble, and artificial shores (Orviku, 1992). Sandy shores are the most dynamic ones

providing about 16% of the nearly 3.800 km long total coastline of Estonia (figure 3). The activities of the sea and ice are clearly visible on sandy beaches located in the areas of land uplift with maximum rate of 3 mm/y (Vallner et al., 1988; Kall et al., 2016). Although surrounded by shallow and tideless (<10 cm) Baltic Sea, storm surges and water level fluctuations shape the near-shore habitats, interfering their further development. Therefore, the presence of vegetation is highly important to resist to all the factors changing the dynamics of coastal dune landscapes. At the same time wind plays an important role: either creating new habitats or moving away available sediment (Ratas et al., 2011; Anderson et al., 2012).

Figure 3. Estonian seashore types according to K. Orviku (1992) and location of study sites (p. 72).

Further inland the changes in coastal dune landscapes have mostly been caused by changes in land use (mainly termination of agricultural activities), which has led to the overgrowth of former pastures with shrubs and forest. Nearly half a century under foreign power (the Soviet military occupation) the coastal dune landscapes belonged to the restricted border zone not accessible to the population, leaving visible traces until present. Nowadays the environment provides an important recreational resource, especially for picking berries and mushrooms, hiking, cycling, and outdoor education.

The aim of the current paper is to analyse general trends of development of grey dunes, which deserve special attention from the conservation and management perspectives. The study was carried out on perpendicular to shoreline landscape profiles in order to express the full spectrum of coastal dune plant communities and surface deposits from shores towards inland. Both, natural and human impacts have been considered in the assessment of changes in the structure and functioning of the grey dunes in Estonia.

Study sites

We selected two study sites in western Estonia to show natural risks and vulnerabilities in the dynamics of coastal dune landscapes (figure 3). At present, both sites are sparsely populated and covered by planted forests. Keibu is located on the NW coast of mainland Estonia, about 80 km from the capital city Tallinn. Ruhnu Island is an isolated location in the Gulf of Livonia, far from the mainland (about 70 km) in SW direction. Regardless of location, both places are extremely popular among both the locals and tourists during the peak season (from May to September). The dynamics of these coastal landscapes has been observed under the National Environment Monitoring Programme and the findings are used in the management plans.

Keibu study site is well exposed to the sea. Keibu area is one of the largest zones of dunes in Estonia and is well known for sandy beaches. This part of the coast is a typical sandy beach with dunes and depressions between them.

Ruhnu study site is located on the eastern coast of Ruhnu Island which is characterised by higher landforms, e.g. dunes covered with pine forest. The most visited beach of the island lies close to the study site and is subjected to greater anthropogenic influences.

Material and methods

The current study is based on the results of fieldwork, existing maps and datasets. We compared geomorphic and topographic maps with aerial photographs and orthophotos and analysed the changes in land cover.

The fieldwork took place in September 2007 and June 2013 at Keibu and in August 2012 at Ruhnu. We used the same landscape profiles positions as in the National Environment Monitoring Programme, focusing our attention to specific habitats.

The relationships of landscape components and biological diversity are demonstrated on landscape profiles (Kont et al., 2016). The changes in land cover can be followed back to the beginning of the past century which reveals the changes in land use as well as in landscape structure (Rivis et al., 2016).

Two profiles orthogonal to the shoreline were selected in order to investigate dune zonation. The lengths of the profiles vary depending on coastal dune landscape morphology. The landscape profile method reveals landscape patterns and relationships between components and expresses the whole spatial structure. Coastal dune landscapes consist of habitats which are highly exposed to physical limiting factors and to anthropogenic pressure. Sample points along the landscape profiles were selected and studied including sampling of different soil horizons and collecting of geobotanical data. The percent of coverage of each vascular plant species was visually estimated in 1 x 1 m plots. The coverage of lichen and moss species was also determined.

Sediment samples were collected for the analysis of mineral deposits and soils along the landscape profiles. The samples were collected from close to the surface (depth 1–20 cm) upper layers as the parent material was rather homogeneous. Grain sizes were determined by dry sieving of the sediments. The sediment samples were dried in an oven at 105°C until their constant weight. Dry samples were sieved for 15 minutes using the automatic shaker Vibratory Sieve-Shaker "Analysette 3" fitted with a standard set of sieves in an interval scale of > 63, 63, 100, 250, 500, 1000 and 2000 in µm. Weights of the sediment retained from each sieve were converted into the percentage of total sediment sample sieved.

Results and discussion

Keibu landscape profile is ca. 500 m long and the maximum height is 8 m. a.s.l (figure 4). The profile is characterised by a sandybeach, white and grey dunes, sandy plains and wooded dunes where more-in-detail study took place with the aim of assessing the character and vulnerabilities of vegetation. The total coverage of vascular plant species compared to other monitoring sites is rather low due to the environmental factors (Ratas, 2007). The rapidly rising seashore is characterised by the presence of typical plant communities in the saline zone (the area of the influence of waves and splashes). Nitrophilous plant communities have developed on the seaweed piles which are under direct wave impact. In the saline zone of the sandy beaches, the common species are sea sandwort (Honkenya peploides), saltwort (Salsola kali) and European searocket (Cakile maritima), which are less permanent due to proximity of the sea. However, the communities in the supra saline zone are usually well developed and species-rich (mainly lichens and mosses).

Figure 4. Keibu landscape profile. Habitat types: 1640 - boreal sandy beaches with perennial vegetation; 2120 - white dunes; 2130 – grey dunes; 2180 - wooded dunes. A - Keibu beach. B - Grey dunes with vehicles tracks. C - Decalcified fixed dunes with Empetrum nigrum (p. 74).

Ruhnu landscape profile is ca. 250 m long and the maximum height is 11 m. a.s.l. (figure 5). The monitoring area is characterised by foredunes, sandy plain and distinctive dunes (Ratas, 2003). The characteristic vascular plant species are sandwort (*Honkenya peploides*), sand ryegrass (*Leymus arenarius*), European marram grass (*Ammophila arenaria*), lady's bedstraw (*Galium verum*), sand sedge (*Carex arenaria*) and blue hair grass (*Koleria glauca*). The dominating lichen species are reindeer lichen (*Cladina arbuscula*) and smooth horn lichen (*Cladonia gracilis*).

Figure 5. Ruhnu landscape profile. Habitat types: 1640 - boreal sandy beaches with perennial vegetation;

2120 - white dunes; 2130 – grey dunes; 2180 - wooded dunes. A - Ruhnu beach. B - Heavy erosion in foredunes. C - Grey dunes with abundant mosses and lichens (p. 75).

Habitats

In Keibu, the sparsely vegetated Boreal Baltic sandy beaches with perennial vegetation (the habitat type 1640) are strongly influenced by active shore processes. A sandy beach is in the immediate vicinity of the shoreline and dominated by patches of *Honkenya peploides* with total coverage varying from 10-35% and accompanied by *Atriplex littoralis*, *Salsosa kali* and *Cakile maritima*. The contemporary beach sediments are mainly medium- (250–500 µm) and fine-grained (100–250 µm) sands.

Neighboring white dunes (the habitat type 2120) are relatively species-poor *Honkenya peploides* (4–10%), *Leymus arenarius* (2–5%) and *Festuca arenarius* (2–3%). The white dunes consist of medium- (250–500 µm) and fine-grained (100–250 µm) sands, coarser particles are rare. The vegetation is under human influence, mainly trampling. Storm surges cause rapid changes to vegetation cover since waves are reaching further inland. Ice-free winters also contribute to erosional processes.

Fixed coastal dunes with herbaceous vegetation (the habitat type 2130) known as grey dunes represent the next stage in the complex. Grey coastal dunes are covered with characteristic species of *Jasione montana* (5–20%), *Honkenya peploides* (5–20%) and *Ammophila arenaria* (5%). The lichen species, mainly from the genera *Cladonia* and *Cladina* grow all over the grey dunes. The dominating moss species are *Ceratodon purpureus* and *Polytrichum piliferum. Cladonia cornuta*, *Cladina arbuscula*, *Cladonia rangiformis* and *Cladonia pyxidata* make up the lichen layer. The sand fractions of the grey dunes are the same as on the beach and in the white dunes. The inland areas are characterised by different wooded dunes (the habitat type 2180) (*Cladina* and *Calluna* forest site type) which are typical to coastal areas high in recreation value. The higher dune in the end of the profile is covered by the habitat type 2140, known as decalcified fixed dunes with *Empetrum nigrum*.

In Ruhnu study site, the sandy beach is strongly influenced by the sea. Active erosion has diminished the area of characteristic species like *Honkenya peploides*. *Cakile maritima* with total coverage of 2–6% is the dominant species on the beach. The contemporary beach consists of medium- (250–500 µm) and fine-grained fractions (100–250 µm) of sand. White coastal dunes are also affected by strong erosion. The dominant species are, first of all, *Ammophila arenaria* (25–30%), followed by *Hieracium umbellatum L.* (10–20%) and *Carex arenaria* (1–5%). The distribution of sediment fractions is similar to the beach. Grey dunes are covered with lichen and moss species with total coverage reaching 80%. The dominant species of vascular plants are *Hieracium umbellatum L.* (10–20%), *Jasione montana* (5–10%), *Koeleria glauca* (7–15%) and *Festuca polesica* (5–10%). Few young pine trees are growing in the area showing an overall trend of afforestation in these landscapes. The sands in grey dunes are slightly dominated by medium-grained particles (250–500 µm) over fine-grained sand (100–250 µm). The inland area is characterised by different wooded dunes (the habitat type 2180) with *Vaccinium vitis-idaea* forest site type which is typical of coastal areas with excellent recreation conditions.

Land cover changes

Landscape fragmentation reflects the spatial variation of land cover. Human-induced changes are reflected in land cover and shaped by land use. Comparison of Keibu and Ruhnu sites demonstrates how landscapes develop in time under socio-economic changes, including the changes in land ownership changes etc. The land cover

in Keibu has been dominated by forest since the beginning of the 20th century (figure 6). During the previous century several disturbances have occurred e.g. forest fire, windfall due to strong storm, planting forest with heavy machinery. Disturbances like these have caused significant changes in the forest (structure, age of the stand, species composition) and in overall landscape development. Coastal dunes are especially at risk due to dryness of dunes in weather conditions which favour the forest fires. Recovery is long due to the harsh conditions.

Figure 6. Keibu land cover changes from 1900 to 2005. A – Example of Keibu study site area on Russian 1 verst (1067 km) maps from 1894 to 1922 (1:42.,000 scale) (p. 77).

The share of forest (figure 6) has remained more or less stable for the last decades indicating no significant changes in protected landscapes over short time, unless logging or forest fires occur. Therefore right conservation and management plans help to preserve coastal forests. The increase in forest decreases the share of open landscapes. Therefore, the landscape becomes more uniform.

An important trend is the decrease of open sand area (figure 6) due to vegetation development and forest planting. Loose sand areas have been controlled by planting *Pinus sylvestris* and also *Pinus mugo*. The increase in forest land has diminished the share of sparsely vegetated territories, limiting different habitat areas and un-favouring their further development.

The general tendency of changes in Keibu land cover is as follows: decrease in swampy meadows, open sand and sparsely vegetated areas and an increase in forest.

Ruhnu land cover shows similar development trends. In the 20th century, the area was mostly covered with mainly pine forest. A major shift in the forest structure was caused by a storm in 1969 resulting in large windfall. Windfalls are quite regular in coastal dune forests. The present land cover is characterised by forest and open sand areas which are primary attractions.

The landscape diversity has decreased due to the cessation of human land use and the predominance of natural processes. Changes in landscapes are mainly triggered by natural processes where some extreme environmental agents act as limiting factors in the development of vegetation. In the future, the main landscape changes will be primarily dependant on recreational use of the island. The land use opportunities here depend first of all on soil- and vegetation cover and landscape diversity.

Coastal landscapes were more diverse in times of moderate land use. Landscape-specific diverse coasts are characterised by certain development trends. Agricultural coastal areas have changed the most following the trends in socio-economic matters. Disappearance of habitual human activities e.g. cropping, mowing and grazing, has led to the overgrowth of the former open landscapes by reed beed, shrubs or forest. The coastal forested areas have been less affected due to nutrient-poor sandy soils.

The study sites are characterised by sands with low $CaCO_3$ content which is common to this region. In dynamic coastal dune landscapes, the initial carbonate content in sand and the meteorological conditions control the rate of decalcification. The contents of organic matter and calcium but also grain size are the main factors determining the capacity of the sand to retain water. The soil pH affects decomposition processes and nutrient flow. From the coastline to inland pH decreases from 6.2 to 4.3. Loose sand in the grey dunes has decreased due to the vegetation cover reaching up to 95% (mainly lichen and moss overlay). The disturbances in vegetation cover under direct impact of anthropogenic factors (trampling, vehicles) have triggered sand mobility.

Management & Conservation

Various studies have shown dune vegetation to be particularly sensitive to human trampling (Stancheva et al., 2011; Santoro et al., 2012) resulting in partial or total destruction of vegetation and also soil compaction. It increases soil density and decreases porosity, an unfavourable condition especially for plant communities of mobile dunes that are adapted to substrate instability and sand burial (Maun, 2004). An increase in sea level could affect dune systems by stimulating the erosion of dune systems.

A combination of a large variety of driving forces, local or regional specificity, interactions between processes and feedback mechanisms might suggest an insurmountable complexity. Every site has its own character and management policy should incorporate this specificity. Erosion is the most important factor of disturbance that causes structural alterations of typical spatial patterns of dune plant communities. Reconciliation of both elements, the increasing development of late successional stages and the threatened biodiversity of open coastal habitats will require an applicable strategy to ensure a mosaic of habitats. This can be within individual sites, but should also take into account the occurrence of habitats on other scales. The optimum scale depends partly on the habitats of interest, and should consider and involve species characteristics such as dispersal ability as well as local scale issues such as soil type, geomorphology and larger background factors such as climate (Provoost et al., 2011).

There is a need for better coordination between national, regional and local administrations to ensure that the development strategies would not ignore the natural values of dune systems and natural development.

Conclusions

Coastal environments need monitoring to assess the level of changes to create knowledge based conservation plans and management approaches to sustain these areas. Considering the ongoing climate change, higher storm surges, etc. changes in habitats in these ecosystems are evident. Therefore understanding uncertainties in landscape development projections, it is vital to introduce new working and comprehensive tools to decision making processes concerning coastal zone management. One of these tools is Systems Approach Framework (SAF) which provides a structured guideline for integrating science into decision making in coastal management processes. Involving managers, policy makers, stakeholders and scientists to manage the use of coastal systems in a manner that is ecologically sustainable, economically efficient and provides social equity.

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