Review of the Kubuqi Ecological Restoration Project

A Desert Green Economy Pilot Initiative

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Foreword

Deserts and desert margins are unique, highly adapted ecosystems that support important plant and animal diversity as well as over 500 million people – nearly 8 per cent of the global population. One of the harshest terrains inhabited by humans, they can also be a major driver of innovation.

The Kubuqi Desert, the 7th largest desert in China, is almost completely encircled by the Great Bend (Ordos Loop) of the Yellow River in the west, north, and east. Situated at an altitude of 850–2130 meters above sea level, it is a unique geographical feature, with a sandy and denuded landscape contrasting sharply with the adjacent areas.

The Kubuqi Ecological Restoration Project of Elion Resources Group, located in the Kubuqi Desert, is a tremendous example of perseverance and innovation creating new Green Economy options. Setting up any business in the area is difficult; creating a business that is both economically and environmentally sustainable requires true ingenuity. Temperatures there can range from -32.1 ºC to 38.7 ºC with sandstorms occurring on over 13 days per year and annual precipitation averaging only 280 mm. Mobile dunes account for 61 percent of its area and the majority of its surface is covered by loose fine sand. Climate change and geomorphological processes exacerbated by human impacts have prompted desertification.

Globally, long-term vision and planning are needed to steer a path away from over exploitation and degradation to an alternative, more balanced path of sustainable development.

In the areas covered by the project, a system that uses both local knowledge and modern innovation has reversed the main form of desertification allowing mobile dunes to stabilise into semi-anchored dunes. From modest beginnings in the late 1980s, the experiment gradually evolved to create a project that has implemented green engineering developments over large areas of the desert, benefiting enterprises, farmers and pastoralists. A pharmaceutical industry has been built around the harvesting of desert plants and a building materials industry developed based on the ecosystem's raw materials, supplemented with investments in renewable energy. An eco-tourism industry has been established owing to the increase in biodiversity as well as an interest in the desert green economy achievements.

This report describes the historical, political and geographical context of the project, the technical innovations, and the private-public-community partnerships that made the greening developments possible. The sustainability of the project was appraised using innovative analytical practices to synthesize the evidence of ecological, economic and social costs, benefits and risks. The report identifies key factors that led to the success of the project and distils principles for sustainable desert green economy projects.

I hope these insights will stimulate the design of sustainable green economy projects in other desert and dryland regions worldwide to enable local communities to benefit from desert ecosystem services.

Achim Steiner

United Nations Under-Secretary-General and

Executive Director, United Nations Environment Programme

Kubuqi Green China Dream

Executive summary

A key element of the Rio+20 declaration was the agreement of countries to consider green economy as one of the important tools available for achieving sustainable development and eradicating poverty. Deserts perhaps pose one of the most challenging situations for implementing a green economy approach, due to the harsh, unpredictable environmental conditions, fragile ecosystem equilibrium, inherently low production potential, and limited infrastructure. Despite these challenges, from 1988 Elion Resources Group (Elion) took up restoration[1] of part of the Kubuqi Desert, located in Hangjin Qi, within the Ordos City prefecture in Inner Mongolia Autonomous Region, China, which later developed into an example of desert green economy. The achievements to date have been remarkable and have attracted much international attention. However what were the factors that led to the success of the project and to what extent could the principles be applied to other dryland areas? The objective of this review was to provide a scientific assessment of the Kubuqi Pilot Site[2] with respect to the project's ecological economic and social sustainability with a focus on private-public-community partnerships.

This report is divided into two parts: Part 1 provides the background and a description of the Elion Kubuqi Project and Part 2 provides an appraisal of the impacts and sustainability of the project, summarized in the form of an economic risk-return model.

Part 1 starts with a brief introduction on the importance of green economy and the potential for the approach in drylands and deserts. Overviews of the geopolitical history and geography of the Kubuqi Desert are given to provide context. The desert ecological restoration activities are then described as well as the associated enterprises. There is a section dedicated to describing the development and nature of the private-public-community partnerships that made the project's achievements possible.

Part 2 first describes the modelling methods.The evidence of on-site and off-site environmental impacts and risks associated with the project are summarized as an input to the model before describing the modelling results. Conclusions are drawn on the overall sustainability of the project, critical success factors and considerations for scaling out desert green economy.

The development of the Kubuqi Project and its enabling factors cannot be fully understood without knowledge of the geopolitical history of the region. The turbulent history of the area due to wars, punctuated by periods of stability with farming and pastoralist activities, illustrates the prerequisite of a stable political environment for desert development. From 1950, during the collectivization phase, radical changes took place in clarifying land property rights and there was a series of policies enacted on land management and desertification control. From 1978, during the decentralization phase, collectivized land was distributed to farmers and the family was re-established as the main body of agricultural operation. Markets started developing and a series of laws and policies were put in place to support desert restoration, both from central and local government. Private sector involvement in desert reclamation started during this phase and Elion established itself as a pioneering company in desertification control and promotion of desert management. From 2000, development of local government policies for ecological restoration intensified further. Private enterprises, notably Elion, transitioned from promoting sandification prevention and control in the Kubuqi Desert to capitalizing on desert resources to develop grass and forest production enterprises to support industrial ecology, and related enterprises.

In terms of geography, the Kubuqi Project Area is characterized by a temperate continental arid

[1] The term "restoration" is taken to refer to re-vegetation and land improvement for the purposes of desertification control and commercial production. Historical records show that the Kubuqi Desert has gone through cycles of greenness and barren desert as a result of both climate changes and human activity.

[2] The Kubuqi Ecological Restoration Project, or pilot site, refers to restoration activities carried out by the Elion Resources Group in the Kubuqi Desert.

climate. Average temperatures range from -11.7 ºC in January to 22.1 ºC in July, with an average annual precipitation of 280 mm concentrated in the months from June to August. Since the 1970's there has been a trend of increasing average temperatures and a decrease in the number of sandstorm days per year. Water supply in Hangjin Qi amounts to 716 million m^3 of which 38% is groundwater.

Ecological restoration efforts were initiated in the late 1980s by the current standing committee member of the Chinese People's Political Consultative Conference, or former Vice President of the All-China Federation of Industry and Commerce, and Chairman of Elion Resources Group, Mr. WANG.The original purpose of planting trees was a sand control programme to protect a salt field and factory managed by Mr. WANG. However drifting sand and shifting sand dunes wreaked havoc with transport of the salt to the nearest railway station. Mr. Wenbiao put forward a proposal to build a 65 km highway connecting the factory to the Wula Mountain railway station. The government supported the scheme and Elion invested RMB 70 million. There was little experience to draw on and the project started by bulldozing the road foundation, but the works were quickly covered with wind-blown sand and shifting sand dunes.

Early tree planting initiatives to protect the road largely failed due to poor seedling survival. Elion subsequently implemented a successful biological package for sand control consisting of fences of straw gathered from agricultural areas and laid out on a grid pattern adjacent to the road, and trees of *Salix linearistipularis* K.S. Hao (Willow), *Caragana microphylla* Lam. (Pea Shrub) and S*alix psammophila* Z. Wang & Chang Y. Yang (Desert Willow) planted along both sides of the road. They extended planting to a 4 km wide green shelterbelt along the 65 km road, consisting of *Glycyrrhiza glabra* L. (liquorice), Salix and other trees. Critical to the successful establishment of trees was the innovation of new planting methods such as air and water jetting.

These initial conservation activities were extended to support a modern pharmaceutical enterprise based on medicinal herbs, initially liquorice, but later including a wide variety of herbs. A range of technical innovations were developed by Elion, including in partnership with a wide range of research institutions, for establishing various herbs, shrubs and trees in various planting arrangements, such as mixed species forests and shelter belts. Advanced drip and pivot irrigation systems were introduced and used to irrigate liquorice, herbs and greenhouse vegetables and fruit. Forage and feed crops were planted to expand the livestock industry, linked to biogas power generation. Organic fertilizers were developed from various organic wastes and biochar.

The highway was extended to a network of trans-desert highways with a total length of 234 km and power, water and telecommunications facilities were installed along them and to surrounding areas. The desert roads enabled access to markets and created new jobs in the area. Elion built the Elion Oriental School as well as improved housing units. Today, Elion Natural Pharmaceutical Group has six pharmaceutical distribution companies in Ordos city. Elion also built up an enterprise based on building materials from sand and is also making investments in the solar and wind renewable energy enterprises, including a large-scale photovoltaic power station. Desert eco-tourism has expanded based on development of the Lake Desert Park and the Lake Desert Hotel.

Public-Private-Community partnerships have been the foundation of the success of the Kubuqi Project. Since 2000, enterprises have replaced elite households (those with strong influence) as the main investment force in sandification prevention projects under the government's pro-enterprise policies. The community of over 100,000 farmers and pastoralists have been one of the largest beneficiaries of Elion's green economy activities through various means, including renting land, becoming shareholders, and developing activities such as tourism, and forestry and farming. The initiative in Ordos has conducted over one million person days of training of ecological reconstruction workers and catalysed collective action by local farmers, the community and private companies in desert ecological restoration. Currently private companies now implement 90% of the afforestation in Ordos, and Elion's investment has become relatively minor. Partnerships with scientific research institutions have been key to the project's technological advances in desert restoration and Elion is increasingly playing an international advocacy role, including through UNCCD and UNEP.

Applied Information Economics (AIE) was used to assess the ecological, economic and social costs, benefit and risks associated with the project. The method assesses uncertainties in costs and benefits, using probability ranges, and outputs a distribution of net present values of the investment.The results of the analysis were used to assess the sustainability of the project, guide where further information collection is merited, determine useful metrics for monitoring project impacts, and identify considerations for establishing desert green economy initiatives in other regions.

Evidence for the project's environmental impacts was assessed as an input to the risk-return model. In terms of on-site environmental impacts, the shelterbelts helped reduce wind, and aeolian sand movement into the Yellow River, and improved the local ecological environment, such as soil condition. The total annual external water consumption beyond rainfall over the project area was estimated as only 1.2 mm water depth per year, or less than 0.7% of the total annual rainfall.

In terms of off-site environmental impacts, there is strong evidence that the frequency and severity of dust storms have reduced in Hangjin Qi, while satellite data on vegetation show increasing greening trends during the 1980s and 1990s. The ecological environment in Kubuqi Desert has apparently been remarkably improved and has become an ideal wetland habitat for migratory swans. Although local experts report rainfall increases due to greening in the project area, meteorological station records do not indicate any changes in rainfall amounts over the past fifty years.

There were no observations available on water table depth in the project area, but according to local residents the groundwater table has slightly decreased in places where the groundwater table was close to the surface. The irrigation water for afforestation activities comes from the confined aquifer and is sustainable if the pumping amount remains less than the recharge amount. Assuming that the irrigated tree planting areas will increase by 1,000 km^2 in the next 10 years, the whole project area irrigation water demand will increase from the current demand of 7.14 million m^3 to 9.54 million m^3, assuming no change in climate. Compared with an available water supply of 40 million m^3, the hydrological risk of tree planting activities in the near future seems to be low. However this analysis does not consider other water uses and demands over the next 10 years, for example demands from cities upstream. A more reliable risk analysis would require a more complex model to include multiple water uses and priorities at a regional scale. Local experts consider the risk of decline in water quality to be low with the current irrigation practices.

In terms of other risks, there is no evidence for increased salinity or alkalinity, or observations of any major plant pests and diseases. However, the Yellow River Basin is susceptible to climate change, especially as it is fed from snowmelt from the Tibetan Plateau, which is sensitive to increases in temperature, but the variation among the predictions emerging from climate change models make the degree of sensitivity difficult to assess.

The Applied Information Economics model generated an average net present value (NPV) of the ecological restoration investment over 50 years of $1.8 billion benefit, but with a 12% chance of a negative NPV. The largest cost is the initial cost of restoration whereas the irrigation costs are small by comparison, and agricultural revenues dominate the benefits. The social benefits of the project are greater than captured in this model considering the continued social investments of Elion, which were significant. Water table draw down was identified as the largest single risk to the project. In a slight majority of scenarios (55%), the water table is stable – that is, water inflows to the water table equal or exceed outflows. In 70% of scenarios, the water table would decline less than one meter over fifty years. In only 2% of cases was the water table exhausted over a 50-year period. Simulation of the risk of decline in future income was simulated using a loss exceedance curve. The simulation generated some drop in income in 7.5% of scenarios from the time period between 2015 and 2065, mostly to a risk of overuse of the water table on agricultural incomes.

The model indicates that expansion of the desert greening to adjacent areas is likely to provide a similar return and risk as past investments. When the Kubuqi Project first started, initial investments would have been in the range of $350 to $600 per hectare. Further expansion is expected to cost 20% to 80% less on average but will depend on the degree to which expansion is into areas with less favourable water resources. The primary risk is the risk of long-term over-exploitation of the water table as the project area expands.

Several key conclusions were drawn from the model results. Similar projects may be justified in other parts of the world in areas similar to the Kubuqi Desert depending on access to a sustainable water supply. Monitoring of water table depths is a key recommendation in the current and new project areas. More comprehensive modelling of the hydrology of the area is recommended as high priority. Continued investments in water saving technology and utilization of plant species that have low water use are also recommended to reduce hydrological risks. Restricting the area planted under large trees, and maximizing the area planted to adapted shrubs and grasses, will be a critical risk-reducing component of this strategy.

A number of geographical, political and social factors have combined to lead to the success of the Kubuqi Desert green economy model. The groundwater conditions in the project area have created a favourable environment for tree establishment and growth. These conditions have arisen because of the proximity to the Yellow River and the geology of the area, and availability of a source of irrigation water from confined adjacent aquifers. The high degree of scientific and technical innovation in tree selection, breeding, establishment, irrigation, and management has been key to the greening initiative. The sand barrier technology was critical for protecting the investments in infrastructure, which in turn stimulated markets and further investment. The high level of scientific and technical innovation extended to the pharmaceutical and sand industry and allowed productive use of desert resources (plants and sand). This in turn stimulated investments in social infrastructure such as improved housing, services and schools.

Government enabling policies were paramount in facilitating private and community involvement and strong partnerships. Elion in particular played a major role in balancing ecological improvement and business operations as well as infrastructural co-investments. Long-term vision and thinking have been critical, especially given the long time frames (20 – 30 years) required for realisation of benefits from tree planting interventions. Forming key partnerships with scientific and technical institutes contributed to technological innovation. An adaptive learning process has been a key feature of this public-private-community partnership. Finally, this report distils from the results of the review a set of ten principles for scaling our sustainable desert green economy projects to other regions.

PART 1 PROJECT DESCRIPTION

1 Introduction

A key element of the Rio+20 declaration was the agreement of countries to consider green economy as one of the important tools available for achieving sustainable development and eradicating poverty. UNEP defines a green economy as one that results in “improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities”. In a green economy, growth in income and employment are driven by public and private investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services (UNEP 2011a). This is especially important for poor people whose livelihoods and security depend on nature. Critical to achieving green economy is to create the conditions for public and private investments to incorporate broader environmental and social criteria. China’s commitment to transitioning to a green economy is evident from the 12th Five-Year plan (2011-2015), which puts emphasis on green investment.

Perhaps one of the most challenging situations for implementing a green economy is in drylands, and especially desert environments, due to the harsh, unpredictable environmental conditions, fragile ecosystem equilibrium, inherently low production potential, and limited infrastructure (UNEP 2006). Desertification—which occurs when land degradation processes acting locally combine to affect large areas in drylands—is a global environmental problem (UNEP 2007). About 2 billion people depend on drylands, 90 percent of them in developing countries; and about 10% of drylands, or six million square kilometres, have already been affected by land degradation (MA 2003). Dryland degradation, measured in terms of loss of net primary productivity, is most widespread in the Sahelian and Chinese arid and semi-arid regions (Zika and Erb 2009). In addition, northeast China shows a trend of increasing aridity and therefore increasing climatological desertification risk, based on an analysis of aridity and climate maps for the periods 1951-1980 and 1981-2010 (Sipinoni *et al.* 2014).

Green economy could provide an opportunity for reversing desertification and improving livelihoods in dry regions, through improved resource management, making use of modern technology and innovative water saving strategies to promote areas such as renewable energy, irrigated agriculture, desert cities, and eco-tourism (UNEP 2006). UNEP’s Global Deserts Outlook concluded that the challenge remains to develop long-range integrated plans that harness market incentives to develop a viable future for deserts, where both environmental conservation and economic development are achieved.

As early as 1988, Elion Resources Group (Elion) began restoration of part of the Kubuqi Desert, located in Inner Mongolia Autonomous Region, China, in an initiative that developed into an example of Desert Green Economy. Through an innovative model of private-public-community investments an area of more than 5,000 km^2 has been afforested through planting trees, shrubs and grasses (Elion 2014). Planting of high value herbs, such as liquorice, is now supporting a large scale, natural pharmaceutical industry. Economic development includes infrastructure development, eco-industries and green agriculture, manufacturing of new building materials from sand, eco-tourism, and renewable energy sources such as solar power. Social development has included building of new homes and schools, and development of cultural programmes. Ecological restoration has resulted in reduced dust storms and sandification, and restoration of the degree and extent of biodiversity. The Kubuqi Project has provided a model of desert green economy.

The objective of this review was to provide a scientific assessment of the Kubuqi Pilot Site with respect to the project's ecological, economic and social sustainability, with a focus on private-public-community partnerships, and to identify key factors for success of desert green economy. The results are intended to guide the setting up of desert green economy projects in other regions. The Applied Information Economics methodology (Hubbard 2014) was used to assess uncertainties, using probability ranges, in the ecological, economic and social costs and benefits of the Kubuqi Pilot Project. The results of the analysis were used to guide where further information collection is merited, determine useful metrics for monitoring project impacts, and identify considerations for establishing desert green economy initiatives in other regions.

2 Geopolitical history of Kubuqi Desert

The development of the Kubuqi Project and its enabling factors cannot be fully understood without knowledge of the geopolitical history of the region. This section provides a brief chronology of the physical and human geography of the Kubuqi desert region and especially land policies that provided an enabling environment for desert restoration activities.

2.1 Early history

The Kubuqi Desert is located in Hangjin Qi and Dalad Qi in the Ordos prefecture of the Inner Mongolia Autonomous Region of the People's Republic of China. It lies to the northern edge of the Ordos plateau and along the south bank of the Yellow River. The name “Kubuqi” stems from the Mongolian language, and means “string of bow”. The Yellow River bounds the Kubuqi Desert on the west, north and east sides, taking the shape of Chinese words “ 几 (ji)”, and appears like a bow suspended over Hanggin and Dalad Qi. Meanwhile, the southern edge of the Kubuqi Desert running from east to west appears like the bowstring (Figure 2.1).

At the beginning of the late tertiary and quaternary geological period (65.5 million to 2.6 million years ago), due to the Himalayan orogeny and the influence of the Ordos plateau uplift, the southern and northern parts of Ordos sagged into a depression and formed deep lacustrine sediments. During the start of the quaternary Pleistocene (2.2 million years ago), the world entered into the great ice age and experienced a series of environmental changes, alternating between wet and dry as well as warm and cool climates, which resulted in the formation of the Kubuqi Desert.

By the end of the early Pleistocene (2.4 million to 730,000 years ago), the warming climate with high humidity gave rise to warm temperate forest grassland or forest environments. However, the climate turned dry and cold in the middle of the Pleistocene (730,000 to 12,600 years ago), with the result that airborne material accumulated in the Ordos region. The strong winter wind eroded and roughened the surface, forming accumulations of airborne materials, which were the early rudiments of sand dunes in the Kubuqi Desert. In the late Pleistocene (126,000 to 10,000 years ago), the climate continued to turn colder. Due to the influence of the ice age, the sand material developed into flowing sand dunes, which strengthened the development of the Kubuqi desert. During the Holocene (11,700 years to present), conditions again became warmer and more humid. The snows in the Yinshan Mountain melted and flowed into rivers and lakes. Ordos gradually produced thriving

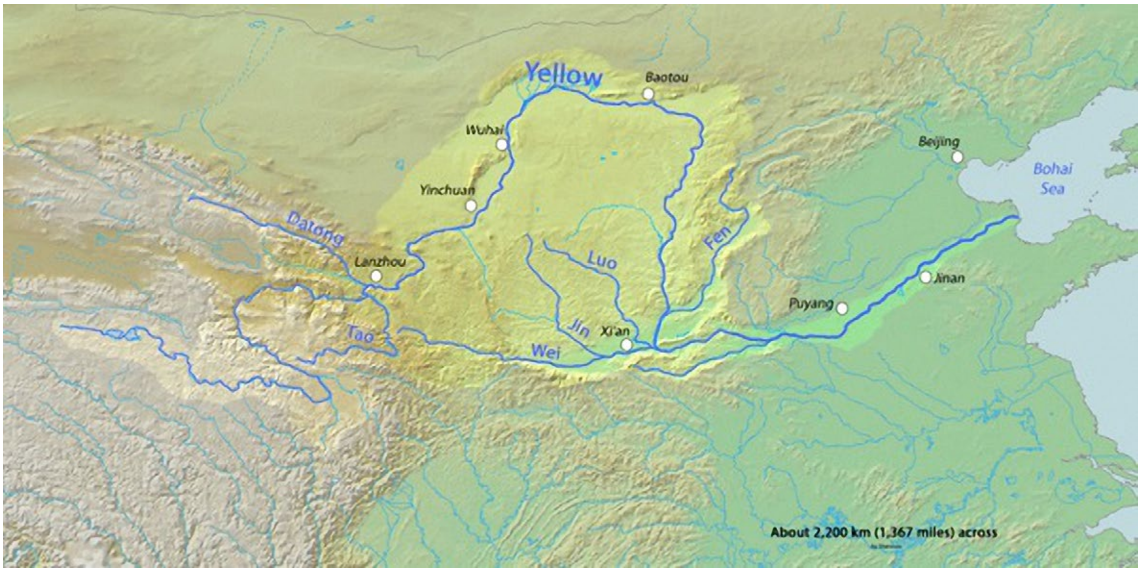


Figure 2.1. Map showing the bow in the Yellow River, which bounds the northern edge of the Kubuqi Desert.

grasslands and lush forests. The vegetation in this area was covered with wet meadow steppe and shrub, which produced dark soils and fixed the mobile sand dunes.

Human activity mirrored the climatic and corresponding vegetation changes. Early human activities dated back to the Pleistocene period (50,000 to 37,000 years ago) (Li 2012). There were alternating cycles of crop cultivation, pastoralist and mixed systems (Table 2.1), often interrupted by wars and large fluctuations in population. There were periods of reclamation and cultivation as well as desertification (Dong and Xin 1992) (Table 2.2). For example records indicate that the Dalad Qi and Hangjin Qi in Kubuqi were under fertile land covered by dense forests in the Qin (221 BC-206 BC) and Han (206 BC-220 AD) Dynasties. Forests were mainly composed of Chinese pines, oriental arborvitaes (Thuja genus of coniferous trees) and needle junipers. Even today there are remnants of juniper forests in the Shihela Valley and Qingdamen Township.

Table 2.1. Alternating farming and pastoralist activities in the history of Ordos culture.

Cultural era	Time period	Human activity
Yangshao culture	7,000 BP - 5,000 BP	Sedentary agriculture early on; then alternating between cultivation and pastoralism
Alternate culture between Longshan and Yangshao	5,000 BP - 4,500 BP	Alternating between cultivation and pastoralism
Longshan culture	4,500 BP - 2,500 BP	Sedentary agriculture early on; then alternating between cultivation and pastoralism
Bronze culture	3,500 BP - 2,200 BP	Sedentary agriculture early on; then alternating between cultivation and pastoralism
Iron Culture	2,000 BP - 1,700 BP	Sedentary agriculture in Qin and Han Dynasty, then alternating between cultivation and pastoralism
Wei Jin and Southern and Northern Dynasties Period	220 AD - 589 AD	Pastoralism
Sui and Tang Dynasties Period	581 AD - 907 AD	Alternating between cultivation and pastoralism
Western Xia regime and Yuan Dynasties Period	1038 AD - 1368 AD	Alternating between cultivation and pastoralism
Since the Ming and Qing dynasty	Since 1368 AD	Alternating between cultivation and pastoralism

Source: Yan 2004, revised by Liu Jinlong

However, the Gejina Oasis is reported to have turned into desert gradually after the Han Dynasty. During the Qing Dynasty (1616-1911) areas along the river in Dalad Qi were described as having luxuriant wild willows, reeds and grasses. In the mid-Qing Dynasty, clearing of forests and burning of grasslands for farming resulted in a decrease in vegetation cover and in desertification of pastures and grasslands.

Ordos's population fluctuated substantially in history: for example the population of Ordos reached 1.3 million at the time of Emperor Hanwu (156 B.C. to 87 B.C) while it was only 100,000 in the Eastern Han Dynasty (up to 220 AD). By comparison the resident population of Ordos reached 1.94 million in 2010. From historic accounts it is difficult to separate the effects of climate change from those of human population pressure on causing cycles of desertification.

Table 2.2. Reclamation and cultivation history in Kubuqi.

Time	Description
270 BC Northern and Southern Dynasties	Huns engaged in farming
206 BC - 220 AD	The Han dynasty strengthened the management of the Ordos region through large immigration, reclamation and cultivation. In the late Han Dynasty, there were records about drift sands.
156 BC - 87 BC	Emperor Hanwu attached substantial importance to the development of Hetao region. He took a series of measures to govern this region. For example, he had a garrison of troops and peasants opened up wasteland and grew grain. He also encouraged immigration. As new agricultural areas were developed, all trees in Ordos were cut down.
5 AD - 22 AD	During the period of Wang Mang, due to inappropriate regulations and policies, the Huns started wars and many farmers went back to their hometowns. In the East Han Dynasty, the population of Ordos reached more than 100,000 people, which caused desertification in sandy grasslands.
581 AD - 907 AD	During the period of Suitang Dynasty, the rulers had garrisons of troops or peasants who opened up wasteland and grew grain.
1662 AD - 1722 AD	In the Qing Dynasty, especially after Emperor Kangxi, the authority enacted policies and regulations to encourage reclamation and cultivation.
1950 - 1998 AD	There were three periods of reclamation and cultivation: 1. In 1959, the government emphasised grain production and implemented substantial reclamation and cultivation in grasslands. 2. During the cultural revolution period (1966-1976) the ruler encouraged nomads and pastoralists to reclaim and develop grassland. Reclamation and cultivation was introduced in the military as well. 3. From 1989 to 1998, the cultivated land in Inner Mongolia Autonomous Region expanded to 2,310 million hectares. These cultivated lands had been high quality natural pastures in the past.

Source: Elion Resources Group based on historic sources

2.2 Collectivization Phase: 1950-1983

After 1950, radical changes took place in land property rights. The central government played an important role in ecological reconstruction, economic development and improvement of people's livelihoods, which had a profound effect on desertification control. During 1950 to 1983, the Kubuqi Desert was included in state-owned land while traditional pasture and croplands were classified as collective land, which essentially belonged to administrative villages. However, due to the vastness of the desert, the boundary of the state-owned land and collective land was indistinct, and the boundaries among communities were also not clear.

In the collective management system, if collective land was in a barren state then local governments could encourage people to afforest land and restore vegetation. In order to promote Kubuqi Desert afforestation, the Hanggin Shilazhao Desertification Control Centre was founded in early 1959 to promote desertification control in the west of the Kubuqi Desert. Subsequently, desertification control centres were established in Hanggin Gaigengzao, Hanggin Haoraocaidamu, Hanggin Alucaideng, and Hanggin Ganzhu Miaoningtiao. A mechanization forestry station was also established at Yikezhaomeng in 1979 and was responsible for a desertification control project in the centre of Kubuqi. The extent of desertification control was estimated to cover an area of 840 km^2. The area under state-owned land increased rapidly until 1983.

In 1958, the central government formulated the *Northwest China and Inner Mongolia Autonomous Region Desertification Control Plan.* According to this plan, the central government recognized that desertification was not only due to natural factors but also due to human activities, including felling of trees, overgrazing and inappropriate land use practices. The plan combined practices of planting trees and grass in shifting sand, fixing sand dunes, protecting existing vegetation to prevent sandification, channelling water, and removal of sand in sensitive areas. The government also employed rotational grazing and block grazing systems. Government policies supported the basic fuel requirements of the population to reduce reliance on trees for fuel. The plan established a desertification governance system, which comprehensively coordinated land governance and utilization and desertification prevention, which still plays an active role in combating desertification in China.

In response to the regulations and policies of central government, local government formulated the *Kubuqi Desert Control Plan* from 1960 to 1969, and the *Integrated Management Plan for Agriculture, Water, Grazing and Forestry,* with emphasis on sand control in the 1970s. These plans and forest regulation policies encouraged individuals in the region to plant trees, grass and vegetables, known as *Four Sides Plantation*[3]. According to the policies and regulations, during the collective period individuals or communities planting trees in *Four Sides* would be awarded the property right of those trees. At the same time there were penalties for deforestation. Every village in Kubuqi had dense tree plantings. Due to the planting of trees along the banks of the Yellow River, which also prevented drift sand from entering the river, the area became known as the “locked in north”.

There were also many policies restricting or prohibiting reclamation and cultivation. In the early 1950s, the government enacted regulation clearly preventing forestland from reclamation and cultivation, and local government called on government departments, communities and social groups to participate in afforestation. From 1958 to 1960, state-owned forest farms and sand control stations were established to protect the forests in Kubuqi. The government took part in the desertification control activities and directly promoted afforestation, also involving the local militia and the youth. From 1964, the

[3] Four sides plantation refers to people planting trees along both sides of the river course, in residential areas, roadsides, and sides of dwellings.

government of Yike Zhao Meng (a prefecture which later became Ordos City) defined areas that could be used as farmland and demanded that farmers plant trees and grass on land that was unsuitable for farming.

As a result of these guidelines, policies and measures, village greening and greening projects along the banks of the Yellow River made great progress. However, despite these efforts, desertification had generally become severer and local residents suffered the consequences. Some leaders of local government made decisions to promote opening of land for cultivation in order to solve food deficits, which contributed to further desertification. Unclear definition of collective land ownership and excessive restrictions on use of collective land also impeded the development of effective management of land degradation.

There was new realization of the need, not only for a long-term effective system for the prevention and control of desertification and for stable policy support, but also innovation in appropriate technologies. A government-oriented platform for cooperation was built for technology supported by scientific research departments, local governments and local communities.

2.3 Decentralization Phase: 1978-2000

China's program of economic reforms (*Reform and Opening Up*) from 1978 started from the rural areas. The collectivized farms and pastures were dissolved, animals, land and other properties were distributed to farmers, and the family was re-established as the main body of agricultural operation. Though the government dominated economic, social and ecological developments, the functioning of markets became more prominent. The growth of China's economy largely relied on a dynamic private economy and a mixed economy. A large number of large private and mixed enterprises, including Elion, were established based on the foundation of an abundant local natural and labour resource, which grew through the transformation and acquisition of local state-owned and collectively owned businesses that were not performing well. This progression had a significant bearing on the management of the Kubuqi Desert.

In 1979, the Inner Mongolia Autonomous Region became one of the first regions in China to implement a household-responsibility system. Starting in Kubuqi in 1980, farmland was divided into 'food provision (for households)' land and 'responsibility' land, where in collectively owned land was contracted to individual farming households. From 1982 to 1983, collectively owned animals were distributed to farming households. In 1984, management rights of collectively owned forest land and ownership of forests were distributed to farming households. In 1989, the policy of *Double Rights and One System* was enacted, which brought clarification of ownership of grasslands, the use right of grasslands, and the household responsibility system. In 1994, the government auctioned barren hills and un-reclaimed lands to farmers and private business. The use rights of part of the collectively constructed state-owned forest land and desertification control sites were returned to the community, and the land was run by the community or distributed to farming households. While the land belonged to the state or the community, products from the land belonged to the farming households. The use rights of land were also transferred to enterprises, social organizations, and large households who could contract land. This property right structure formed the basis for enterprise-community collaboration and involvement of businesses in desertification control.

The central government and local government of the autonomous region issued a series of policy papers including *Decision on Tree and Grass Plantation, Decision on Reformation Enhancement and Forestation Promotion, Notice on Economical Policy Issues of Pasture Areas,* and *Instruction on Tree and Grass Plantation and Pasture Landscape Construction.* The policy papers focused on tree and grass plantation enhancement, prohibition of wasteland reclamation, pasture protection, and desertification control management. This series of papers demonstrated the significant attention from the central and local governments of the autonomous region to desertification control. Policies included mobilization of local government institutes, social groups, private businesses, and local communities in wind reduction and sand fixation. Policies such as *Around the house, Wasteland and Sand Land Forestation, The Construction Person, The Management Person, The Owning Person,* and *The Inheriting Person,* motivated farmers on tree planting and afforestation.

With the guidance from these policy papers, since 1979 a number of programmes were implemented in the Kubuqi Desert, including the *Three North Forest Shelterbelt Construction First Phase Programme (1979), the Sandification Control Ten Year Plan (1991-2000),* the *Three North Shelterbelt Construction Second Phase Programme (1985-1986),* and the *Three North Shelterbelt Construction Third Stage Programme(1986-2000).* The programmes integrated scientific research, experiments, capacity building, economic incentives, administrative awards and punishment, monitoring and evaluation, community construction, and partnerships. Implementation of the plans expanded the scale of sand control and resulted in remarkable ecological, economical and social benefits.

Local governments became more conscious of the importance of involving private business and individuals in ecological reconstruction for sandification prevention and control. Local government ensured that wherever possible land was contracted to households, through clarification of the rights to control, manage and obtain benefits. This motivated enthusiasm for public protection and grassland reconstruction, thus helping to guarantee the anticipated benefits and sustainability of the projects. The combination of ecological protection and industrial development of farming favoured sustainable intensification of farming and increased farm income.

As the market became a more important factor in the growth of China's economy, there was increased demand for legislation to guarantee socio-economic development and ecological reconstruction. China's legislative institutions developed a number of laws, including the *Forest Law, Grassland Law, Water and Soil Conservation Law, Land Management Law,* and *Environmental Protection Law.* Central and local government developed detailed rules and regulations for the implementation of the laws, for example, after the introduction of the Grassland Law, several legislation instruments were developed as a follow up, including *the Inner Mongolia Autonomous Region Grassland Management Regulation,* and *the Inner Mongolia Autonomous Region Pasture Protection Regulation.* The *Law of the People's Republic of China on Desertification Prevention and Control* was implemented, which was the world's first specific legislation instrument on desertification prevention and control and clearly defines rights and obligations of land users in control of desertification. This preliminary law system on desertification prevention and control provided a legislative framework for Kubuqi Desert conservation.

Public promotional activities have played an important role in conservation. In 1979, the 12th of March was assigned as *Tree Planting Day* in China to promote afforestation of the country and improve the environment for sustainable development for future generations. For example, Hangjin Qi implemented the tree planting event each spring and autumn, whereby leaders mobilized community labour forces. Government sectors, legislative bodies and civil society were contracted to organize the public in tree and grass planting, developing a strong organization and accountability system. Company social responsibility complemented individual and local government contributions. Elion was initiated in this social context and has proved the most remarkable company among those involved in desertification control, providing a significant force in promoting desert management.

Technological innovation from government research also played an important role in desertification control strategies. Technologies included water saving systems for small farming households, advances in crop breeding and planting techniques, improved grazing methods, development of small-sized agricultural implements, improved tree and grass planting and management methods, crop cultivation techniques, and the integration of these various techniques. Ecological constraints, such as lack of water resources, fragile ecosystems, and low quality land, were tackled through development of techniques that used less water and land, intensified cultivation to relieve stress from grazing lands, and development of economical forestry and integrated watershed management systems.

2.4 Private enterprises enrolled in desertification governance: 2000 - present

Ecological restoration has been a key strategy in the China government's western development from 2000. The central government has adopted a series of policies and measures such as increasing investment and promoting the development of private enterprises to control desertification. Emerging private enterprises such as Elion have played an important role in desertification control and governance in the Kubuqi Desert with the support of local government in terms of policies, planning, and infrastructure construction.

A number of desertification control projects have been initiated, such as the third phase of the construction of the shelter forest system, named *Three North*, the Sand Control Project, the Soil and Water Conservation Forest Project located in the middle and lower streams of the Yellow River, the Ecological Environment Construction Project, and the conversion of Cropping Land to Forest and Grassland Project. From 2001 to 2012, the local government began to implement comprehensive forestry protection programmes, which in addition to returning farmland to forest programmes, included the Natural Forest Protection Programme, the fourth period of *Three North*, the Wildlife Protection and Nature Reservation Programme, the Japanese Yen Loan Project, and the Demonstration Area Construction Project for sand prevention and control. The government also promoted policies on grazing prohibition and controlled grazing. In terms of livestock, policies on barn feeding and half barn feeding have been enacted, which have renewed sustainable animal husbandry practices in grasslands. Under the *Two Properties and One System*[4] policy, the government has allocated pastures and meadows to residents and carried out grazing bans and rotational grazing. This policy significantly reduced livestock pressure on pasture land, changing

[4] Clarification of ownership of land, use right of land and household responsibility

land use patterns of nomadic tradition that had been practised for thousands years. Policies on planning, investment and finance have also supported involvement of private enterprises. For example the *Ordos City Forestry and Sand Production Plan* was implemented from 2005 to 2010.

Private enterprises, notably Elion, have transitioned from promoting sandification prevention and control in the Kubuqi Desert to capitalizing on desert resources to develop grass and forest production enterprises to support industrial ecology and enterprises such as the sand industry and solar energy. The philosophy followed can be translated as “more light, less water, new technology and high benefit”. Elion also provided much support and encouragement to the farmer and pastoralists communities for planting trees, grass and traditional Chinese medicinal herbs. Greening the desert improved the value of resources and enterprise efficiency and increased farmers income and government tax revenue. These developments are described in more detail in Sections 4 and 5.

3 Geography of the Kubuqi Desert and Kubuqi Project Area

3.1 The Kubuqi Desert

The Kubuqi Ecological Restoration Project (the Kubuqi Project)[5] is located in the Kubuqi Desert in the Hangjin Qi of the Inner Mongolia Autonomous Region. The Kubuqi Desert is located in the northern edge of the Ordos Plateau, and south of the Great Bend of the Yellow River, and is part of the Ordos Desert (Figure 3.1). The Ordos Plateau is a unique geographical feature consisting of a sandy and denuded landscape, contrasting sharply with the adjacent areas, with altitude ranging from 850 m to 2130 m above sea level. The Kubuqi Desert is the 7th largest desert in China, bordering the Maowusu Desert in the south of Ordos. The Ordos Desert is almost completely encircled by the Great Bend (Ordos Loop) of the Yellow River in the west, north, and east, and its terrain slopes gently from south to north. Mountain ranges separate the Ordos from the Gobi Desert north and east of the Yellow River.

The Kubuqi Desert extends 400 km from west to east and 50 km from north to south with an area of 14,500 km^2 and altitude of 1200 to 1400 m above sea level (Figure 3.2; Du *et al.* 2014). Mobile dunes, mainly trellis dunes and chain dunes, account for 61% of its area. The surface is covered by loose sand, and more than 81% of the surface sand particles are graded as fine sand (0.1–0.25 mm). From 1956 to 2011, the average annual temperature was 6.6 °C, with diurnal mean temperature ranging from a maximum of 31.2 °C to a minimum of −25.7 °C (Du et al. 2014). The annual precipitation is approximately 300 mm, 60% to 70% of which occurs from July to September. Evapotranspiration is low in winter due to the low temperatures. Strong winds occur frequently in spring months (March–June), and the diurnal maximum wind velocities exceeded 10 m/s at a height of 10 m on more than 30 days in every year from 1972 to 2011. Saline and sodic soils are common in the area.

Given the erodible sand surface and the strong winds, aeolian processes, especially aeolian saltation, are severe (Figure 3.3). Aeolian sediments are deposited and stored in the Ten Tributaries (Figure 3.2) during the

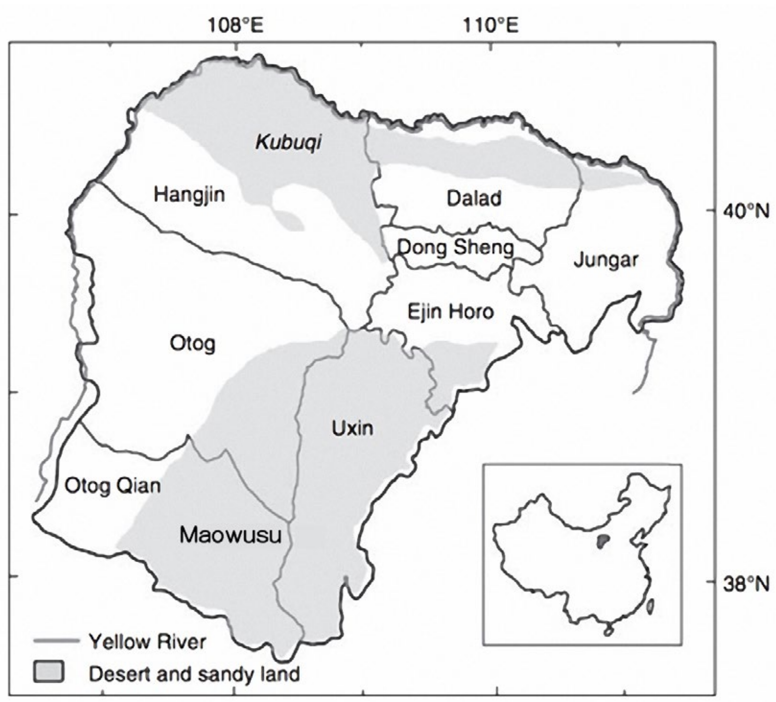


Figure 3.1 The Ordos District of Inner Mongolia Autonomous Region.
Source: Zheng and Li 2009.

[5] The Kubuqi Ecological Restoration Project, or pilot site, refers to restoration activities carried out by the Elion Resources Group in the Kubuqi Desert.

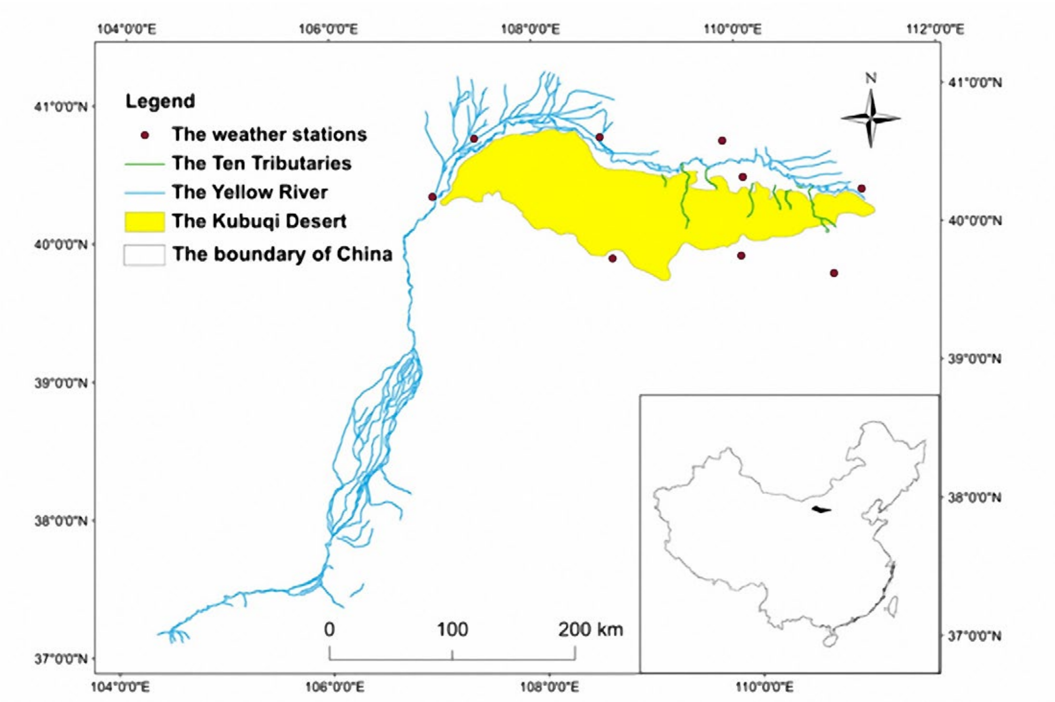


Figure 3.2 Sketch map of the Kubuqi Desert and the Yellow River.
Source: Du *et al.* 2014[6].

windy seasons, and floods wash some of the sediments away during rainstorms. The extremely concentrated flows commonly destroy railways, highways, and factories, and the sediment may cause serious silting in the Yellow River (Du *et al.* 2014).

The harsh and challenging conditions for human habitation of the Kubuqi Desert were evident from historic accounts from the Tang Dynasty (618–907 AD) of "three feet deep sand here stops horse from travelling". Up until two decades ago the desert was known as "the barren land". A review of desertification in China by Wang *et al.* (2008) and Tao *et al.* (2011) summarise the evidence for desertification trends in the Ordos Desert. Although the Ordos Desert is well-known as a "human-made" desert, historical records from ancient China and archaeological evidence, suggest that the desert existed at least 4,000 years ago, long before large human populations lived in this area. There have been several phases of desertification and rehabilitation that parallel climatic changes. Monitoring data shows that from the mid-1950s to the present, the desertification extent (in terms of dune formation) in the Ordos Desert has decreased steadily, from 68% of the area in the mid-1970s, to 63% in the mid-1980s, and 54% in 2000. The main form of desertification has been the evolution of anchored dunes into semi-anchored dunes, and rehabilitation has seen the reverse evolution of mobile dunes into semi-anchored and anchored dunes. The population of livestock (sheep and goats) and the human population have increased continuously over the past 50 years in this region, but significant rehabilitation occurred after the 1980s despite these pressures. Wang *et al.* (2008) conclude that desertification is likely to have been prompted by climate change and geomorphological processes, even though human impacts have undeniably exacerbated their effects.

[6] This image was published in Du *et al.* 2014, copyright Elsevier.

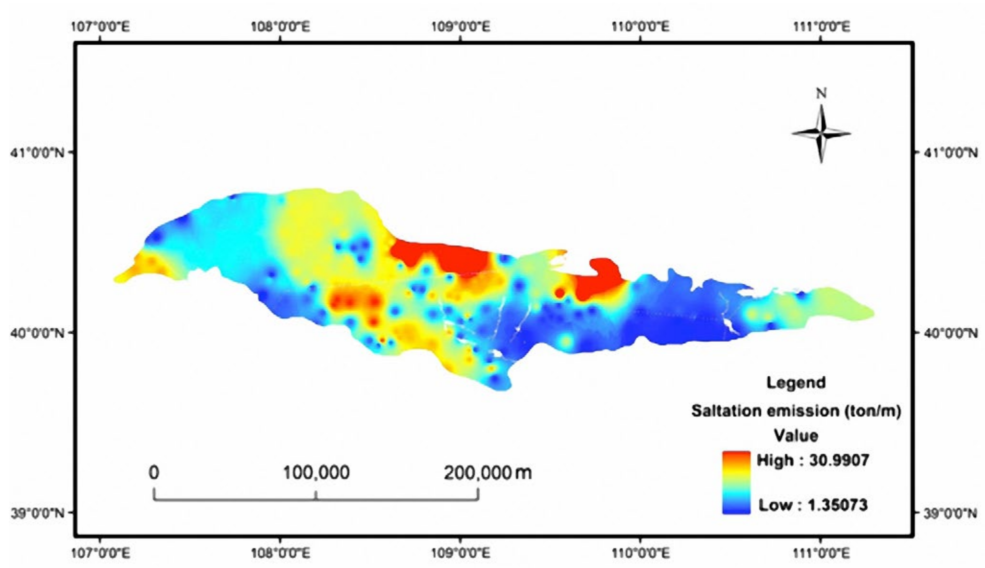


Figure 3.3. Spatial distribution of estimated total saltation sediment emissions (tons) in the Kubuqi Desert over 10 years (2001 to 2010). Source: Du et al. 2014[7].

The Ordos landscape is made up of areas of shrub-grassland (53%), woodland (17%), cultivated fields (6%), with the remainder of land (24%) not suitable for agriculture (Frisina *et al.* 2001). Important crops include corn, sunflower, millet, potatoes, wheat and flax. The vegetation of Ordos rangelands is typical of arid environments and includes a diversity of plants (91 families, 340 genera, and 647 species). Shrubs, including a number of *Caragana* species, and types of sagebrush dominate the desert steppe, with feather grasses and forbs in years when there is suitable moisture. Frisina *et al.* (2001) provide a list of the more important plant species for stabilizing sand dunes, as well as dominant wildlife species. The latter include 20 key species of mammals and 113 main bird species. Sheep and goats comprise about 90% of domestic livestock, which numbered about 8 million in 2000. Family farmsteads derive their livelihoods from mixed agriculture in community-based systems that involve close cooperation between families and villagers. Farm sizes are from 14 to 20 ha with 20 to 30 goats and sheep in farming areas, and from 100 to 160 ha with 100 to 150 goats and sheep in pasture areas. In pasture areas, 12 to 20 ha will typically be put under forage crops to aid in sand dune control and for wood production (Frisina et al. 2001). Willow tree prunings are stored as winter forage and trees pollarded for poles for house construction.

[7] This image was published in Du *et al.* 2014, copyright Elsevier.

3.2 The Kubuqi Elion Project area

3.2.1 Geographical location

The Kubuqi Elion Ecological Restoration Project is located in Hangjin Qi, which is in the north-west of Ordos City (a prefectural level city, although mostly rural) in the Inner Mongolia Autonomous Region. Hangjin Qi covers an area of 18,914 km^2, extending between latitudes of 39°22′ to 40°52' N and longitudes of 106°55′ to 109°16′E. It is surrounded to the west and north by the Yellow River (Figure 3.4), is adjacent in the East to the Dalad Qi, Dongsheng City and Yijinhuoluo Qi, and to the South borders with Wushen Qi and Etuoke Qi. The Hangjin Qi administratively consists of five towns, Baragon town, Huhemudu town, Jirigalangtu town, Duguitala town, and Xini town; and two counties: Yihewusu Sumu and Byanneour.

The Kubuqi Desert spans across the north central part of Hangjin Qi and divides it into two parts: along the Yellow River and the Liangwai region. The area along the Yellow River is one of the most important grain commodity bases of the country, and is also the largest gravity irrigation area along the Yellow River. The Liangwai region is an important production base of animal husbandry in Ordos City prefecture.The Kubuqi Project includes 8,000 km^2 of the Kubuqi Desert. The natural vegetation is sparse and comprised of drought-resistant and salt-tolerant shrubs and grasses, as described by Frisina *et al.* (2001).

3.2.2 Meteorological conditions

The Hangjin Qi is characterized by a temperate continental arid monsoon climate (Köppen class BWk, desert climate), with a long cold winter and warm short summer, and a windy spring and cool autumn. January is the coldest month with average of -11.7ºC and extreme minimum temperature of -32.1ºC. July is the hottest month with average of 22.1ºC and extreme maximum temperature of 38.7 ºC.The annual average temperature is 6.4ºC. The average annual precipitation is 280 mm, unevenly distributed across seasons, however rainfall during June, July and August accounts for 65% of the annual total. The annual water pan evaporation is 2,630 mm, of which nearly 74% occurs during May to October. The wind speed increases from northwest to southeast, with frequent gales (24.6 days per year on average) in the spring. There are sandstorms on 13.2 days per year on average.

Based on weather data from the Hanggin meteorological station (39° 51’ N, 108° 44’ E) from 1959 to 2013, the interannual and decadal variation of precipitation, temperature, gales and sandstorm days are shown in Figure 3.5 to Figure 3.10. The interannual precipitation and gale frequency show little time trend, while temperatures have increased, and the number of sandstorm days per year have decreased dramatically since the 1970s.

Figure 3.4. Satellite image showing the Yellow River which bounds Hangjin Qi to the North and areas of greening. Areas to the north of the river are masked out. The image is 70 km across.

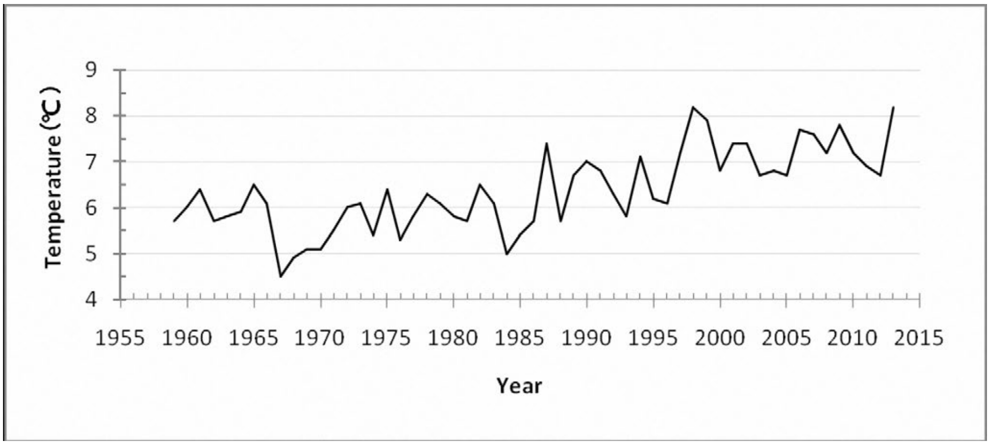


Figure 3.5. Annual air temperature at Hangjin Qi weather station (1959-2013).

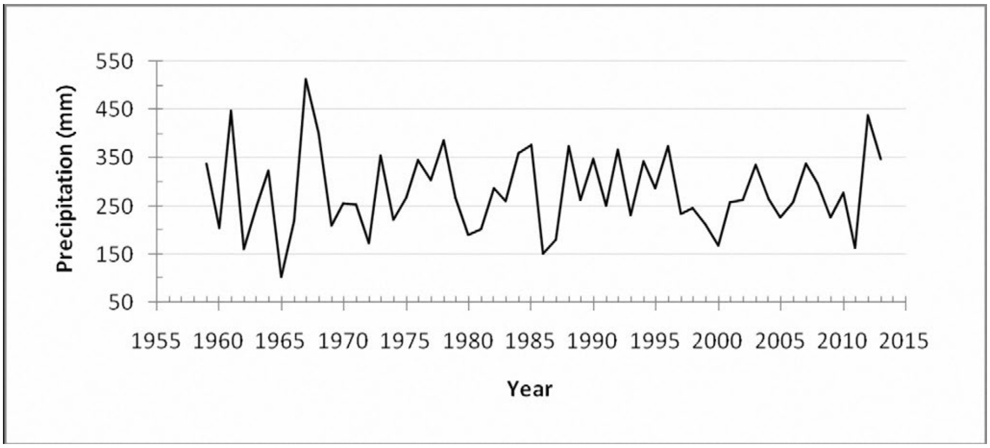


Figure 3.6. Annual precipitation at Hangjin Qi weather station (1959-2013).

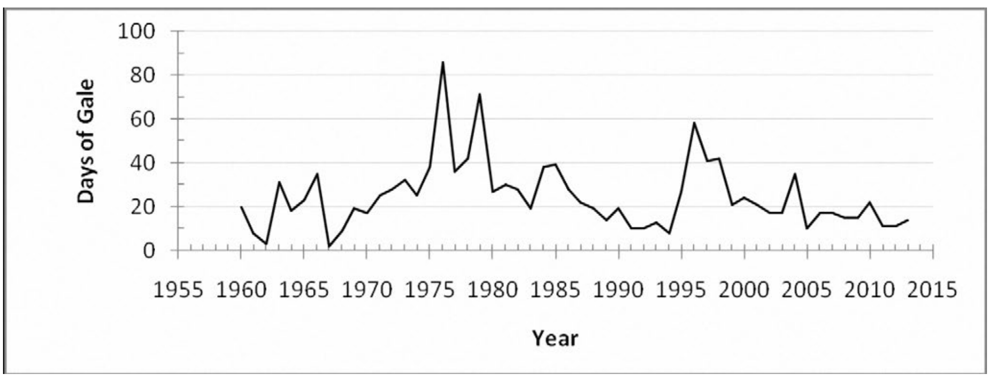


Figure 3.7. Annual gale days at Hangjin Qi weather station (1960-2013).

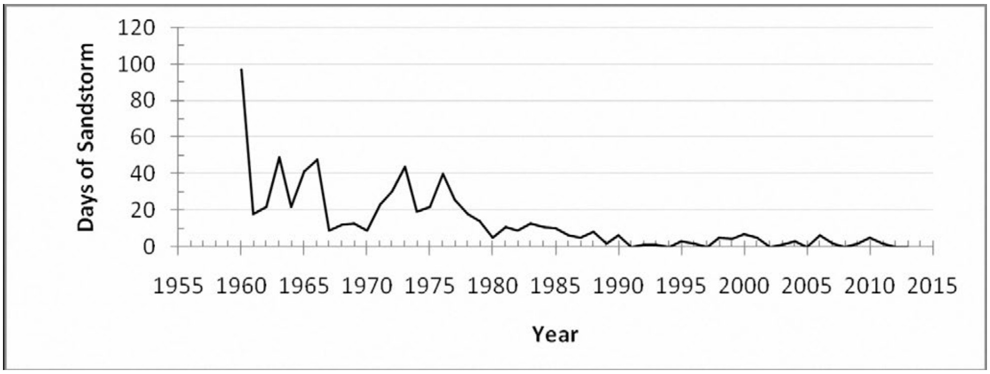


Figure 3.8. Annual sandstorm days at Hangjin Qi weather station (1960-2013).

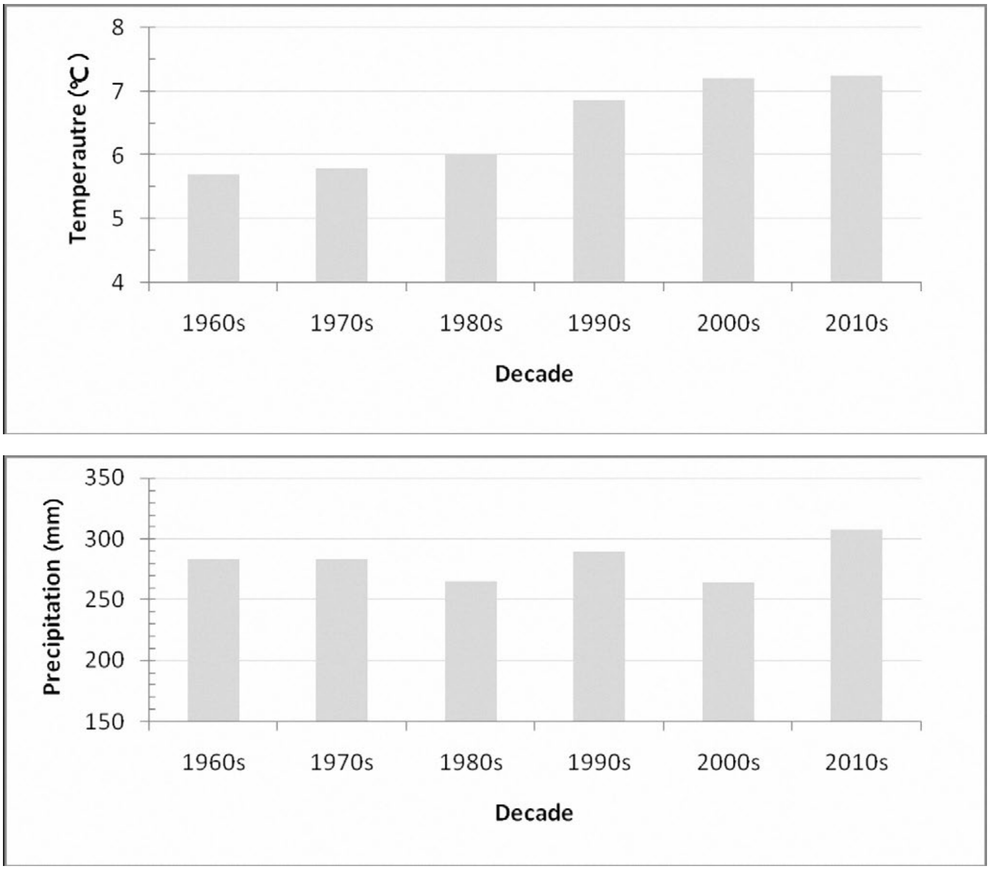
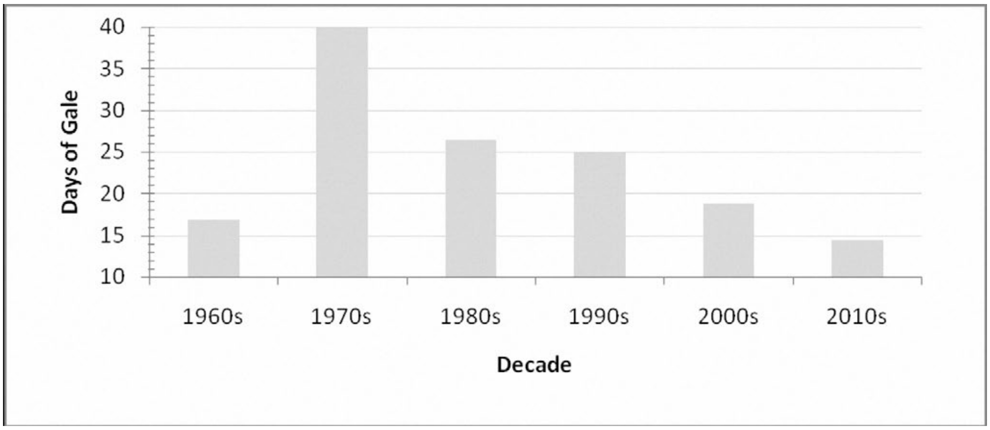


Figure 3.9. Annual average temperature (top) and precipitation (bottom) for each decade in Hangjin Qi.



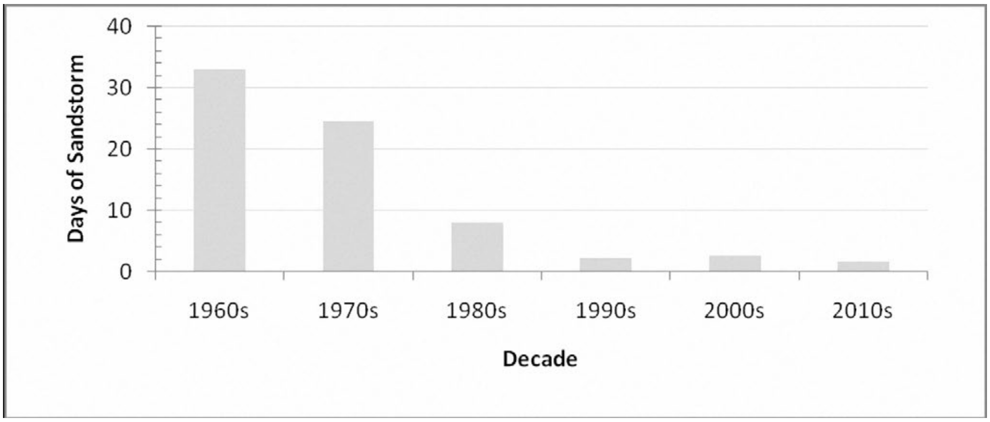


Figure 3.10. Annual gale and sandstorm days for each decade in Hangjin Qi.

3.2.3 River systems

There are 25 rivers in the region, including Yellow River, Balagon Ditch, Maobula Ditch, Shakoumoren River, and Taolai Ditch. These rivers can be divided into two types: ocean rivers, which include Yellow River and its tributaries, Balagon Ditch, and Maobula Ditch; and inland rivers, which include Shakoumoren River and Taolai Ditch. The Balagon Ditch is a seasonal river with a catchment area of 70.4 km^2, gully length of 27 km, and annual average runoff of 232,300 m^3. The Maobula Ditch is also a seasonal river, with characteristics: catchment area of 1,262 km^2, channel length of 111 km, stream gradient of 4.4%, annual average runoff of 7.57 million m^3, annual average sediment transport of 2.1 million tonnes, soil erosion modulus of 1,660 t/km^2, and runoff modulus of 6,000m^3/ km^2/yr. Yellow River is a pass-through river along the west and north borders of Hangjin Qi, with 90-120 days of freezing, average annual runoff of 30.6 billion m^3, and average sediment discharge of 124 million t. The inland Molin River has a catchment area of 5,220 km^2 (about 3,220 km^2 in Hangjin Qi), with river length of 81 km, stream gradient 2.07%, annual average runoff of 8.61 million m^3, and sediment discharge of 84,000 tonnes. Taolai Groove is 86 km long, with stream gradient 4%, a watershed area of 905 km^2, and annual runoff 3.62 million m^3. The data sources are the Hangjin Qi Water Conservancy reconnaissance design team, and the Hangjin Qi water resources master plan (Inner Mongolia Autonomous Region 2005).

3.2.4 Water resources

Water resources are limited in Kubuqi Desert due to the desert climate. The total amount of water resource is 451 million m^3, accounting for 19.1% of the total for Ordos City prefecture. The water resources in the southern hilly area and central area are less than in the northern plain area, for both surface water and groundwater.

Hangjin Qi is relatively rich in water resources in the Ordos Plateau. Yellow River flows along the northern borders of four towns and one county in Hangjin Qi, with a river length of 254 km. The annual river discharge is 3,100 million m^3, of which the Yellow River Conservancy Commission assigns 410 million m^3 to the Hangjin Qi for agricultural irrigation use.

According to water resources data from Hangjin Qi, the water supply and demand balance for twelve water demand units in 2005 and that projected for 2010 resulted in a total water supply of 715.8 million m^3, consisting of 272.9 million m^3 of groundwater and 442.9 million m^3 of surface water (Table 3.1). Water resource supply is greater than the demand in seven units, but there are five units with water deficit. The water surplus areas area are mainly distributed in the area along the river and in Bayinwusu County and Liangwai.

Table 3.1. Analysis of water resource supply and demand (million m^3/yr) in Hangjin Qi showing areas in surplus or deficit.

Assessment Unit	Available water resource		Base year (2005)		Planning year (2010)	
	Groundwater	Surface water	Demand	Surplus or Deficit	Demand	Surplus or Deficit
Hangginnore County	31.44	11.60[1]	28.168	14.872	41.441	1.599
Duguitala Town	36.42	18.20[1]	39.524	15.096	256.228	-201.608
Huhemudu Town	11.35	146.55[1]	146.978	10.922	100.141	57.759
Yihewusu Sumu	51.57	5.864	21.281	36.153	38.316	19.118
Haoraochaidamu	41.73	0.837	19.684	22.919	35.441	7.126
Tarangaole	9.79	2.08	15.303	-3.433	35.400	-23.530
Sishililiang	15.71	0	19.424	-3.714	34.915	-19.205
Amenqirige	3.16	0	10.7434	-7.583	19.354	-16.194
Jirigalangtu Town	16.68	228.45[1]	229.226	15.904	146.280	98.850
Bayinwusu County	43.80	0.415	10.480	33.735	22.396	21.819
Baragon Town	5.27	28.552[1]	28.933	4.889	29.855	3.967
Xini	6.01	0.324	4.459	1.875	7.694	-1.360
Total	**272.93**	**442.872**		**574.179**		**767.459**

[1] From the Yellow River

Sources: Hanggin Water Conservancy Survey and Design Team; Hangjin Qi water resources master plan (Inner Mongolia Autonomous Region 2005).

4 Desert ecological restoration

4.1 How it all started

Ecological restoration efforts were initiated in the late 1980s by the current standing committee member of the Chinese People's Political Consultative Conference, or former Vice President of the All-China Federation of Industry and Commerce, and Chairman of Elion Resources Group, Mr. WANG Wenbiao. At that time (1988) he was the manager of a salt factory located in the salt field of Hangjin Qi. The salt field consists of an 18-km^2 deposit that is not only rich in salt but also mineral resources such as mirabilite and trona. The deposits are located at a depth of 2 to 4 m under the sand and can be turned into industrial salt when washed with brine and re-crystallized. There was no electricity, water, or road infrastructure and the salt mining factory was under constant threat of sand deposition. Mr. WANG started a sand control programme, first to protect the salt field and factory. He reinvested RMB 5 from the profits of every ton of salt to plant trees, deploying a team of 27 forest workers. This appeared to yield positive results.

A bigger problem, however, was transportation. The salt field was only 65 km direct distance from the railway station, but the actual road trip to get there was 350 km at an average vehicle speed of 10 km/hour. The unpaved roads were under constant threat of sand deposition and were constantly changing due to drifting sand and shifting sand dunes. Trucks would frequently get stuck in drift sand and get behind schedule. Much of the profit of the sand mining was lost on transport costs.

A proposal was put forward Mr. WANG to build a 65 km highway connecting the factory to the Wula Mountain railway. The government supported the scheme and Elion invested RMB 70 million. There was little experience to draw on and the project started by bulldozing the road foundation, sometimes through 10 m high sand dunes. However the construction workers would wake up the next morning to find no trace of their previous day's work, due to blown sand. It was realized that a protection package would need to accompany the construction.

Figure 4.1. Aerial view of the project area from the East showing the Yellow River and plantations.

Although it was common knowledge that sand could be stabilized by trees, there was little guidance available on which trees to plant and how. Early attempts at planting drought resistant tree species failed when they died soon after planting, even when more than 20 different desert-adapted species were imported from other countries. These had to be tolerant to drought, cold and soil alkalinity. Using discarded wine bottles to supply water increased survival rate but was inefficient. Mr. WANG then decided to go deep into the desert and learn from the traditional knowledge of pastoralists. He learned about the traditional medicinal herb,

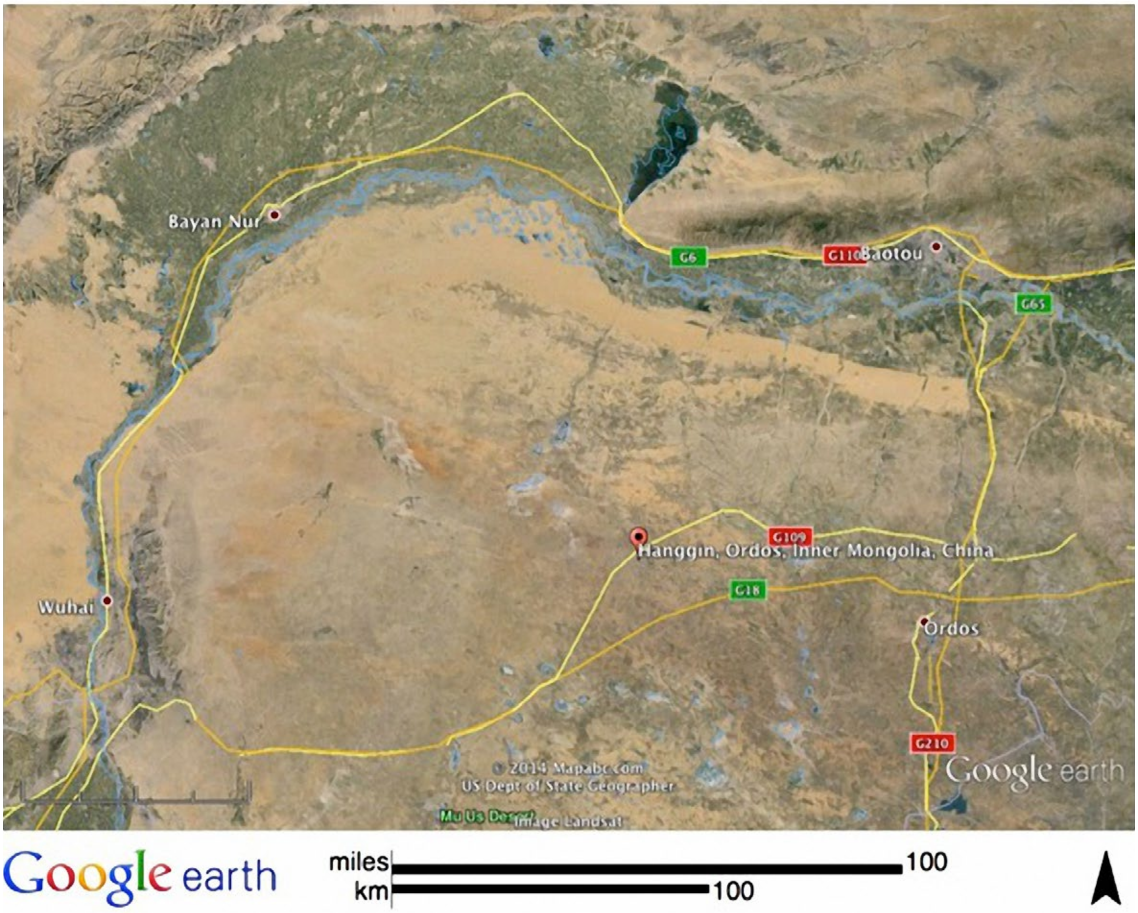


Figure 4.2. Map showing Hangjin Qi in relation to Baotou, the current road network, and the Yellow River.
Source: Google Earth 2015.

liquorice (*Glycyrrhiza glabra* L.), which is well adapted to Kubuqi Desert conditions. His team subsequently deployed a biological package for sand control. This consisted of fences of straw gathered from agricultural areas and laid out on a grid pattern adjacent to the road, with trees of *Salix mongolica* (accepted scientific name: *Salix linearistipularis* K.S. Hao), *Caragana microphylla* Lam., and *Salix psammophila* Z. Wang & Chang Y. Yang were planted along the road. They also planted a 13,340 ha green belt of liquorice along the road, *Salix* and other trees. Critical to the successful establishment of trees were innovative new planting methods such as air and water jetting (see below). The project was completed in three years and created a 65 km long, 4 km wide green corridor, which protected the new tarmac road (Figure 4.1). Power, water and telecommunications were also installed along this first trans-Kubuqi highway (Figure 4.2) and to surrounding areas. The highway allowed the salt factory to prosper, leading to the establishment of the Elion Group, and also brought new opportunities to 100,000 farmers and pastoralists in the region, for example through improved market access and lower cost of inputs, which attracted outside investment and employment opportunities.

4.2 Technical innovations

A number of technological innovations by Elion and other institutions have been critical to the desert restoration process. For example Elion alone has won 13 technological awards (Elion 2013). Over time the number of plant species introduced increased from initially 10 families and 8 species to 20 families and 77 species.

One of the most important breakthroughs for tree establishment was the development of the "vapour method" or "water jetting", which involved jetting water into the deep sand layer to aid planting of the shrub cuttings. Air jetting was also used to create holes in the sand for planting. This increased tree survival rate, from 20% to over 85%, reduced planting costs and even enabled tree planting on high sand dunes (Figure 4.3). With this method a tree could be planted in just 30 seconds and one person could plant 0.5 ha in a day (Elion 2013).

Also key to success was the bundled flat sand barrier technology for stabilizing sand dunes, by bundling *Salix psammophila*, reeds, crop straw and other materials (Figure 4.4). By using a grid pattern of 1 × 1 m or 2 × 2 m and 10 to 15 cm high, the surface roughness was found to be 165 to 190 times higher than control sites. This technology has proved to be simple, rapid,

Figure 4.3. Water jetting planting method being used to plant *Salix psammophila.*

Figure 4.4. Sand barrier technology using a grid pattern of bundled Salix (willow) stems, crop straw and other materials.

low cost, and effective in reducing wind speed and aeolian sand movement. By 2013, the demonstration area of this technology reached more than 33 ha.

The project developed a series of practices for liquorice planting and production, including germplasm resources, seedling transplanting, field management, and best harvest time of the liquorice (Figure 4.5). These included four technical standards (ecological environment quality, liquorice seed level, liquorice seedling quality, and liquorice quality), 160 liquorice production and quality management documents, and 81 standard operating procedures, as well as a number of patents.

Figure 4.5. Liquorice plantation.

From 1998 to 2006, aerial seeding of grass and trees by helicopter was used by Elion to green over 30,000 ha. Different seeds were distributed from different helicopter installations and GPS navigation used to aid the operations.

Stabilizing hillsides to facilitate afforestation may require exclusion of some or all of human activities. Three types of exclosure are established to protect and manage areas of helicopter seeding of grass, according to the degree of exclusion: total exclosure, which forbids all human activities such as grazing and land reclamation from the outset, with the length of exclusion ranging from 5 to 7 years to 10 to 15 years depending on the type of forest; half closed, which allows some human activity during certain seasons, providing this does not cause ecological damage; and rotation exclosures, which rotate the land between total exclosure and half closed.

In 2003, Elion cooperated with the Inner Mongolia Autonomous Region University to develop standardized procedures for planting of herbs *Cynomorium songaricum* Rupr., and *Nitraria tangutorum* Bobrov, for breaking dormancy of *Cynomorium* seeds, and for grafting of *Nitraria.* They determined the main active ingredients affecting the quality of *Cynomorium* and established 200 ha of standardized planting bases of it using this technique.

A vertical planting technology was developed that combines forest shelter belts with medicinal herbs. Liquorice and other Chinese medical herbs are integrated in the shelter belts, which are composed of strips of *Salix psammophila, Elaeagnus angustifolia* L., *Populus tremula* L., (Aspen) and *Ziziphus jujuba* Mill. (Red Date). The project established a system that optimizes utilization of the upper, middle and lower parts of the desert landscape, balancing interests between long-term, medium-term and short-term production, and realizing ecological, economic and social benefits.

An ecologically based industrial chain was developed consisting of planting forage and feed crops to expand the livestock industry, which provides manure that not only produces organic fertilizer but also enables biogas power generation. The off-cuts created when shrubs are pruned to improve their vigour are processed into feed.

Figure 4.6. Using greenhouse technology for raising tree and herb seedlings and growing vegetables.

In terms of plant breeding, Elion cooperates with local governments and residents in a decentralized way, involving companies, cooperatives, farmers and pastoralists. The company provides compound feed and breeding techniques, while cooperatives, farmers and pastoralists are responsible for the actual breeding. Moreover, the company is also responsible for unified purchases and market sales.

Cost-effective methods were developed to restore saline-alkali soils through re-vegetation using saline and alkali tolerant plants. In addition to liquorice, more than 10 species were found to be suitable, including: *Lycium barbarum* L., (Boxthorn), *Hippophae rhamnoides* L., (Sea Buckthorn), *Populus diversifolia* Schrenk (or Populus euphratica Oliv.; Euphrates Poplar), *Elaeagnus angustifolia* L. (wild olive), *Ammannia gracilis* Guill. & Perr. (Ammania), and *Haloxylon ammodendron* Bunge (Saxaul). Impacts of reduced salt content in the soil and improved soil properties are reported (Elion unpubl.).

Greenhouse technology (Figure 4.6) was developed initially for raising seedlings, but later adapted for production of organically grown vegetables such as pepper, tomato, eggplant, lettuce, and cowpea. Advanced drip and pivot irrigation systems were also introduced (Figure 4.7) and used to irrigate liquorice, herbs and greenhouse vegetables and fruit. The water is pumped up from deep groundwater.

A method was developed for manufacturing organic fertilizer from soil, shrubs stalks, crop waste, cow dung, and inferior mined coal. This has already produced 2.6 million tons of organic fertilizers, mainly used for reclamation of salinized land. There is a plan to build an organic fertilizer factory with a production capacity of 5 million tons per year.

In recognition of the importance of conservation of the plant genetic diversity in the region, Elion is establishing a Genetic Resources Centre for Desert Shrubs and Rare/Endangered Plants in Inner Mongolia Autonomous Region. The Centre aims to enhance the collection, evaluation, preservation, and utilization of plant resources in the desert area and further guide the ecological restoration in Inner Mongolia Autonomous Region and Northwest China. This is to include programmes on breeding, germplasm improvement and planting methods and will help to control and regulate the seed and seedling market. Over 70 rare and endangered species are to be conserved, including *Pinus massoniana* Lamb., *Pachytella mongolica picea*

Figure 4.7. Drip and large area pivot irrigation systems. The crop on the right is liquorice.

Heyrovský, *Ulmus pumila* L., *Sabina vulgaris* Antoine, *Tetraena mongolica* Maxim., *Potaninia mongolica* Maxim., *Ammopiptanthus mongolicus* (Kom.) S.H. Cheng, and *Prunus pedunculata* (Pall.) Maxim. The initiative would constitute a major contribution to sustainable development and cultural heritage in the region. Other technical innovations are listed in Appendix 1.

4.3 Plantations

The highway protection project, conducted in 1997 between Elion and the Hangjin Qi government, established an area of 8,000 hectares of closed plantation by erecting a 100 km mesh fence along the roadside. In the adjacent area, 2,453 hectares of sand barrier was established with10 million trees planted, and 4,000 hectares of grass sown by plane. The sand barrier and vegetation has reduced the wind speed by between 17% and 62%, and lowered wind-blown mass by 26% to 71% (Elion unpubl.).

According to the Kubuqi Ecological Restoration Project map (Figure 4.9), prepared by Elion, the more intensive plantations (areas with physically planted trees or shrubs) are geographically located in the area 107°30′ to 109°16′ E and 40°10′ to 40°52′ N, inside Hangjin Qi. The plantation area is mainly distributed in three areas, referred to as A, B and C. Area A is along the north bank of the Yellow River, a strip of 110 km along the river and 20 km wide from north to south. In this area, mainly liquorice and other trees are planted. Area B is in Yihewusum County, a rectangular area of 70 km long in the East-West direction and 30 km wide in the North-South direction, mainly under liquorice. Area C is in Bayannaoer County, a 225 km^2 square-shaped area under tree plantations. All the planted areas are on relatively flat lying terrain and with good water supply (surface water or groundwater).

Along the north margin of the Kubuqi Desert along the south bank of the Yellow River, Elion established 350,000 hectares of shelter forest in a belt of 242 km long and 5 to 20 km wide, consisting of trees, bushes and grass. By adjusting species to the local conditions, suitable tree and grass species were arranged in different areas such as shifting sand dunes, flat sand areas, beaches, and saline-alkali land. Large-area planting included the species: *Elaeagnusangustifolia* L., (Wild Olive), *Caragana korshinskii* Kom. (Pea Shrub, leguminous), *Populus spp* (Poplar), liquorice and *Salix psammophila* (Desert Willow).

There are several kinds of shelter forests in shifting sand coverage areas: (i) shelter forest of *Salix psammophila;* (ii) chequerboard of *Salix matsudana* Koidz. (Sand Sagebrush) and *Salix psammophila;* (iii) chequerboard of *Pinus sylvestris* L., var. Mongolica and *Salix psammophila;* (iv) chequerboard of *Pinus sylvestris* and *Elaeagnus angustifolia* L.;(v) reed sand barrier of *Pinus sylvestris* and *Hedysarum scoparium* Fisch. & C.A. Mey.; and (vi) reed sand barrier of *Pinus sylvestris* and *Salix psammophila.* Shelter forests in inter-dune areas consist of: (i) *Saliz matsudana* and *Hedysarum;* (ii) *Salix psammophila* and *Hedysarum scoparium;* (iii) *Salix matsudana,* (iv) *Elaeagnus angustifolia,* and (v) *Tamarix chinensis* Lour. (Chinese Tamarisk).

Figure 4.8. Shelterbelt plantations along the Yellow River and stabilization of hinterland.

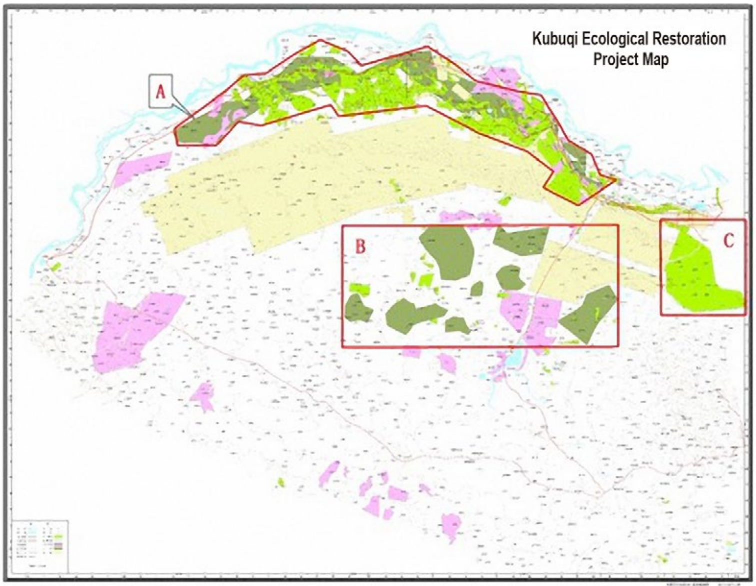


Figure 4.9. Kubuqi ecological restoration area showing major planting areas: A is along the Yellow River, B is in Yihewusumu County, and C is in Bayannaoer County. Light green represents tree planting, dark green is liquorice, and purple is sand-fixing by vegetation.

Chequerboards aid recovery of vegetation by reducing wind and aeolian sand movement, thereby preventing dune movement. This effect is beneficial to the growth of annual pioneer plants on fixed or semi-fixed sand dunes, including *Agriophyllum squarrosum* Moq., *Corispermum hyssopifolium* L., *Bassia dasyphylla* Kuntze, as well as annual plants of *Salsola passerina* Bunge. The growth of such pioneer plants helps the succession of secondary plants and protects the growth of other psammophytes (plants adapted to shifting sands). Plant survival rates in chequerboards are reported by Elion to reach over 80% for *Hedysarum, Salix psammophila, Salix matsudana* and *Caragana microphylla,* and 74% for *Populus deltoides* W. Bartram ex Marshall.

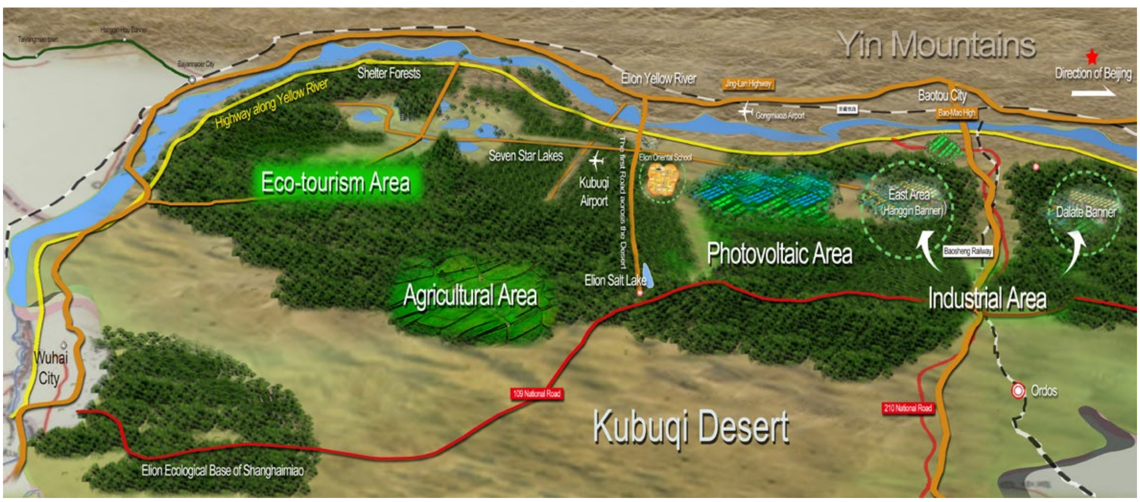


Figure 4.10. Map of plantations on the south bank of the Yellow River (area A in Figure 4.9).

4.4 Production economics

The planting of liquorice and range of other types of xerophytes (plants adapted to desert environments) and herbs supply the pharmaceutical industry and bring annual profits (see Section 4.2). A number of the plants also provide a source of fodder for livestock. The sandy woodland in the experimental demonstration area provides for 1,500 RMB/ha ($240/ha) according to the forest resource evaluation of Ordos. That means the project woodland area has a value of RMB 300 million ($48 million). There are 750,000 ha of *Caragana microphylla* and *Salix psammophila* in the experimental demonstration area. Based on the value of shrub wood in windy desert areas of 280 RMB/ha this plantation is worth RMB 170,880,000 ($27.4 million).

The effects of shelter forests such as wind prevention and reduction, decrease in water evaporation and moderation of regional microclimate, have successfully increased the production of liquorice so providing income and economic benefits. Up to 2013 the liquorice planting technology was applied to the establishment of 80,000 ha of semi-wild liquorice planting bases, 2,500 ha intensive planting bases and over 43,000 ha wild seed collection bases. According to Elion's calculations, shelter forests in the experimental demonstration area can increase the production of liquorice by 16%. Production of liquorice in 2014 was 1,656 tons, with the benefit due to conservation equivalent to RMB 1,050,000 ($168,000).

5 Associated enterprises

5.1 Infrastructure

Following the establishment of the first central highway, Elion adopted a strategy of partitioning the desert with a road system (Figure 5.1). According to this strategy, they built five roads with a total length of 234 km and simultaneously developed related infrastructures along the roads and surrounding areas, including water, power and communications. The roads were supported by a green ecological barrier with a length of more than 242 km.

The Elion Oriental School, built with an investment of RMB 110 million, is a modern boarding school with a high profile, which integrates a kindergarten, primary school, junior secondary school, and vocational education. It is located in the new town of Duguitala and covers a building area of 29,000 m^2 (Figure 5.2).

Figure 5.1. Yellow River highway.

Figure 5.2. The Elion Oriental School and housing.

5.2 Pharmaceutical

Elion Natural Pharmaceutical Group is one of the important industrial sectors of Elion Resources Group. The operation includes three main components (i) planting and processing of green Chinese herbal medicines, mainly liquorice (Figure 5.3); (ii) research and development, production and sale; and (iii) wholesale, retailing and delivery. The company network extends over many parts of China. The total assets of the company are more than RMB 2 billion. In 2013, the income from sales was about RMB 6 billion with profits of about RMB 150 million. A liquorice brand "Liangwai liquorice" has a strong reputation in Japan, South Korea and Southeast Asian countries, accounting for a large share in the food and food additives market. The production and processing of xerophytic plants into natural medicinal plants conforms to the medicinal plants standard of the European Union.

Elion Natural Pharmaceutical Group has three manufacturing enterprises and 500 officially approved products including over 20 Chinese and Mongolian medicine varieties with proprietary intellectual property rights. There are six pharmaceutical distribution companies in Ordos City. The Group has plans to fully integrate the whole industry chain to become the leader of the Chinese and Mongolian herbal industry in China and of the logistics industry for the Chinese herbal materials trade.






Figure 5.3. Pharmaceutical industry based on liquorice.

5.3 Building materials

Elion has the rights to use 120 hectares of aeolian sand resources in Kubuqi Desert, which it has utilized to develop sand-textured coatings that have a natural appearance similar to sandstone. These products have excellent weather resistance, anti-contamination, self-cleaning and flexibility properties (Elion 2013). The product conforms to the national standard JG/24-2000, and can be widely used in various interior and exterior decoration works in the building industry (Figure 5.4). High-end modern automatic production lines have been installed to support the industry.

A composite building material combining PVC with *Salix psammophila* wood fibre is also produced. The composite material combines dual properties of wood and plastic with the advantages of pro-environment, anti-moth, anti-bacterial, flame resistant, and excellent mechanical properties at low cost of production.

Another aeolian sand product produced is an oil fracturing proppant (a fluid and used in hydraulic fracturing). The product has properties of high strength, low density and low friction (Elion 2013). The performance indices of the product conform to the SY/T5108-2006 standard. The product can replace haydite as a dominant fracturing proppant and has obtained 40 national patents.

Figure 5.4. Building materials made from sand.

5.4 Energy

Elion is making investments in the solar and wind renewable energy enterprises in the Kubuqi area (Figure 5.5). The Ordos Zhengli New Energy Power Generation Co. Ltd. is building a large-scale photovoltaic power station of a capacity of 110 MW. It will be divided into two phases, with the first phase being of 10 MW and the second phase being of 100 MW. When in operation, this project is expected to save about 17,650 tons of standard coal each year and reduce annual emissions by about 107 tons of dust, 32,930 tons of carbon dioxide, 241 tons of sulfur dioxide, and 159 tons of nitric dioxide.

In cooperation with the Guangzhou Institute of Energy Conversion of the Chinese Academy of Sciences, Elion has developed a biomass gasification technology based on utilization of biomass resources produced by pruning *Salix psammophila.* In 2013, the gasification demonstration unit had a capacity to use 10,000 tons of Salix biomass.

Figure 5.5. Elion solar and wind renewable energy investments.

Figure 5.6. Kubuqi Seven Star Lakes Desert Park

5.5 Desert Eco-tourism

Kubuqi Seven Star Lakes Desert Park (Figure 5.6) is a desert eco-tourism resort developed in Hangjin Qi by Elion, and is well connected to major roads and three nearby airports. It has a China tourist attraction rating of AAAA and has won a succession of awards, including: "The First Batch of Low-carbon Ecological Tourism Demonstration Areas throughout China", "National Water Recreation Area", "National Desert Tourism Experimental Base", "Ordos National Desert Geo-Park" and "China Desert (Seven Star Lake) Car Cross-Country Training Base". In 2011, it was confirmed as the permanent venue for the Kubuqi International Desert Forum. The Desert Park covers 890 ha, including a water area of 115 ha, a reed wetland area of 41 ha, a grassland area of 380 ha, and a desert area of 384 ha.

Figure 5.7. Seven Star Lakes resort in the Kubuqi Desert.

Figure 5.8. Kubuqi International Desert Forum Convention Centre.

The complex includes the 5-star Seven Star Lakes Desert Hotel (Seven Star Lakes Resort), covering 40,000 m^2 and including 154 rooms with a capacity of 700 people and providing banquet and conference facilities, which receives about 65,000 tourists every year (Figure 5.7); the Kubuqi International Desert Forum Convention Centre (Figure 5.8), covering 14,000 m^2 with a capacity of 1,200 persons and including simultaneous translation facilities; a Desert Science and Technology Museum displaying the most advanced concepts and techniques of desertification control; and a Desert Botanic Garden with more than 500 kinds of endangered psammophytic plants from around the world. The Park's lakes support a variety of waterfowl and water weeds.

5.6 Other enterprises

Other industries include the salt industry and organic fertilizer production, described in Section 4. Elion also established a water company to construct reservoirs. During ice melt, the surplus water from the Yellow River flows into a flood storage area, where the water is saved for irrigation. Industrial wastewater can also be used for ecological reconstruction when disposed of by the water company. The water company aims to make efficient use of water resources including both groundwater and surface water.

5.7 Enterprise interactions

Resource flows among enterprises have been critical to the project's success (Figure 5.9). Products from desert restoration such as liquorice supply the pharmaceutical industry. Infrastructural development has aided desert restoration through better road access, communications and water supply for irrigation. The infrastructure has in turn benefited from the ecological restoration through protection from sandification. Desert restoration also protects the infrastructure of the building materials industry, factories, mines, houses, and schools from sandstorms and sandification. Costs are saved from the reduced need to dredge sand from the Yellow River. Desert restoration has also promoted ecotourism. Among other enterprises the salt industry was a prime driver for the early desert restoration activities, as described in Section 4.1. Profits from all the enterprises feed back to support the desert restoration activities.

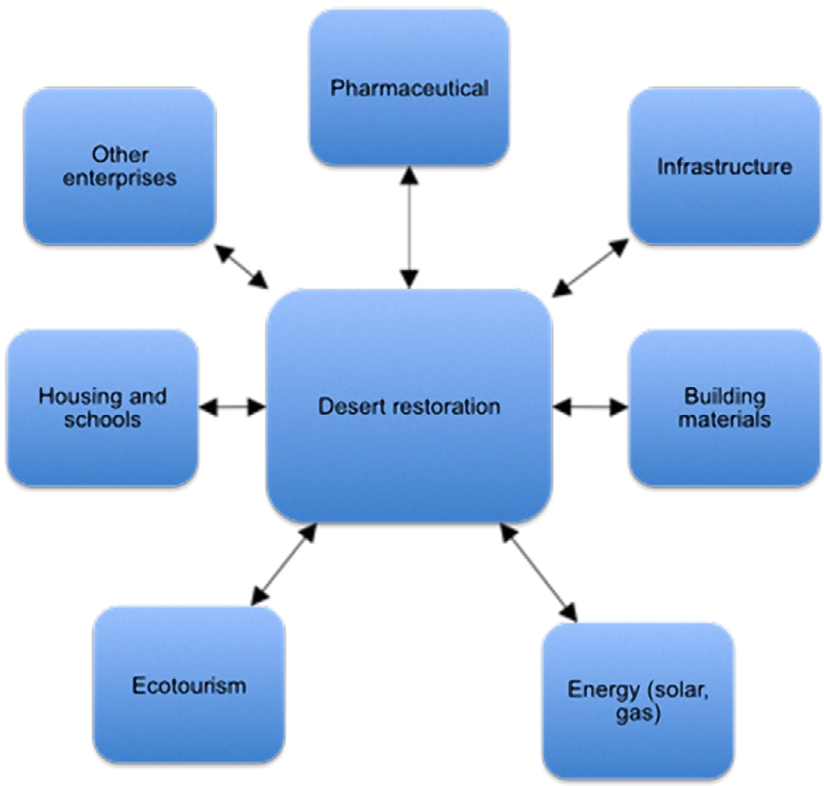


Figure 5.9. The various Elion enterprises associated with the Kubuqi Project.

6 Public-private-community partnerships

Public-private-community partnerships have been critical to the success of the Kubuqi Project. This section describes the historic and institutional background, the relationships between government and enterprise, and the enterprise-community partnerships that contributed to this success.

6.1 Historic policy and institutional background

As described in Section 2, Chinese administrations at all levels gave priority to ecological restoration. They realized that improving the ecological environment is a prerequisite for good livelihoods and regional economic development. In the meantime, governments, enterprises and local communities reached a consensus that improving ecological environment can be realized only after Kubuqi's people have met their basic living standards.

Since the early 1980's, China has promoted de-collectivization and marketization reforms. The central government has gradually delegated powers of fiscal and authority to local government, giving the latter relatively autonomous economic and administrative decision-making power. Prevention and control of desertification in Kubuqi is afforded high priority as a public service, on the level of other services such as education, infrastructure, and social security. Hangjin Qi, where the project is located, was economically under-developed prior to the project. In the late 1990's, the local government revenue was not sufficient to pay for civil servants and teachers' salary and welfare. This forced the government to add extra budgetary revenue. One strategy that local government took to solve the financial difficulties was to auction barren mountains in the late 90's and the proceeds were invested in ecological restoration (see Section 2). Starting from the 1990's, the government clarified use rights of farmland, grassland and uncultivated land and contracted them to individuals. They also adopted the policies *Who Governs, Who Benefits,Who Afforests, Who owns,* and *Jointly Afforest, Commonly Own* to accelerate the speed and efficiency of desertification control.

Local governments used limited resources to minimize inputs and maximize public service outputs of desertification control. In the 90's, prevention and control of Kubuqi's desertification was included in national planning and the projects of *Three-North Shelterbelts* (Section 2). The government provided RMB 75 per hectare of fiscal subsidies to land that had been included in the planning of afforestation. In relation to economic returns, this incentive was not enough to encourage enterprises and the local elites to engage in desertification control. Therefore, people who devoted themselves to preventing and controlling desertification were given additional incentives, such as if the area afforested reached 333 ha and was preserved, then the family or the enterprise would have the right that their children (or a young person) could be employed by governmental affiliated institutions under Hangjin Qi.

Spiritual motivation and recognition have also been driving forces for the private investments to engage in desert restoration. For example, Mr. WANG was awarded the "The Inner Mongolia Autonomous Region Labour Model" title in May 1995. He also won the "Outstanding People of National Afforestation" title and the national "May 1 Labour Medal" in 2000. In 2012, he was again awarded the "Outstanding People of National Afforestation Work Labour Model". In 1995, Mr. WANG was the first person in Hangjin Qi to achieve the Provincial Labour Model for prevention and control of desertification, the only person to be awarded this title by the people of Hanggin. Recognition of the outstanding work of Mr. WANG and his team of Elion Resources Group was honoured during the UN Conference on Sustainable Development, held in Brazil Rio de Janeiro in June 2012, when he was awarded the "United Nations Environment and Development Award". Mr. WANG went on to win the UN Global Dryland Champions award at the 11th Conference of Parties of the United Nations Convention to Combat Desertification in September 2013. The achievements of the Kubuqi Project in the prevention and control of desertification have become well known and regarded in the international community.

Emerging as a centre of China's energy development (mostly coal and some gas), Ordos has become one of the richest regions in China, and this has spurred governmental and public expectations on environmental improvement, sand control and improvement of social services. Changes in government enterprise policies facilitated public-private partnerships. Before 2000 sand prevention projects were predominantly funded by elite households but this posed problems such as inadequate scope, informal organization, imperfect supervision, and high costs. However after 2000, enterprises replaced elite households and become the main investment force in sand prevention projects under the government's pro-enterprise policies. Investments included encouraging land transfer, providing technical guidance, limiting exploitation of mining, protecting ecosystems when building infrastructure, and increasing compensation for ecological destruction, such as from flooding.

Kubuqi also benefited from tax federalism, which was established in the mid-1990s to provide incentives to local government to boost the local economy, as local government and central government were able to share the fiscal revenue from the newly developed GDP. Since Hangjin Qi and Ordos were extremely poor regions in China in the mid 1990s, central and provincial governments heavily subsidized them. Ordos has made impressive economic progress, achieving the highest economic growth rate in China since 2000. Increasing local fiscal revenue as a result of the rapid economic growth has also enhanced local government's ability to provide public services in sand prevention and rural development.

6.2 Public-private partnerships

The management of resources and environment has recently become a heated topic among the Chinese public. The Chinese government has realized that sustainable management of resources and environment is a prerequisite to realize the "China Dream" and is a vital component of public service. However, if the government alone conducts sand prevention projects then they face challenges of complex implementation arrangements, high investment costs, and inefficiencies due to bureaucracy. Public-private partnerships can help overcome some of these limitations.

Elion Resources Group and the government have built a comprehensive partnership with the following features:

1. Financing. The central and local governments provided the necessary policy tools, and established a cooperative framework between banks or financial companies and Elion. This included coordination with the National Development Bank, Agricultural Bank of China, Industrial and Commercial Bank of China, China Construction Bank, and other policy or commercial banks.The framework provided a financial guarantee for Elion's self-development and desert restoration activities.

2. Investment arrangements. The central and local governments opened up some projects to private enterprise, such as public projects for combating desertification, ecological restoration projects and vegetation rehabilitation projects. The Elion group could be a service provider or contractor of the national projects. This brought a new source of profit to Elion. For example, Elion won the bid to build an ecological restoration project for the venue of the Beijing Olympic Winter Games.
3. Technological innovation and services. The government took the responsibility to provide technical services for the Enterprise in the 1990s. However from 2005 Elion became a major participant in technology

research and development of desertification prevention, and actively introduced advanced international technology for irrigation water use and management. At the same time the project collaborated with colleges to develop anti-desertification technology (see Section 4). In 2014 Elion established the Desert Research Institute, demonstrating that enterprises have become the main research developers for anti-desertification and sand industrial technology. Another example is the planned Genetic Resources Centre for Desert Shrubs and Rare/Endangered Plants in Inner Mongolia Autonomous Region. The government only needed to provide the necessary funding or coordination of services and promote the development of industrial technology.

4. Policies and projects. Elion has become a lead stakeholder, participating in all levels of government reforms of anti-desertification policy, institutional innovation and governance.
5. Resource management. Elion has established forest protection systems and cooperated with government related departments to set up a forest police station. Both the forest public security and Elion manage the station, and Elion subsidise the forest Police to work in remote desert areas. This is an innovation in government administration and is beneficial for good relations between Elion and the government.

In summary, in the governance of the desert ecosystem the government provides the public authority; social communities provide labour and guide collective community action to turn desert governance into reality; the enterprises provide the economy and market forces; while the government also protects the interests of enterprises including economic benefits.

6.3 Private-community partnerships

6.3.1 Private enterprise as part of the community

Elion is an integral part of the Kubuqi Desert community. The company first developed in the Kubuqi Desert and its corporate value is rooted there, both in terms of material resources and spirituality. Its connection to the desert has remained strong even though (i) the company's core business stretches much beyond the sand industry, (ii) the corporate headquarter is now in Beijing with obligations covering the whole country, and (iii) their products and services now stand on the world stage. Elion is still considered a “desert enterprise”, which forms an essential part of the corporation’s culture.

The corporate founders and early entrepreneurs are all from the desert communities located in Kubuqi, and Elion has invested heavily in the community’s public infrastructure. Just one example is the Elion donation of $16 million in 2009 to build the Elion Oriental School, which is a modern school specifically for pastoralist’s children,combining kindergarten, elementary, middle school, senior technicians, and Party School. The school accepts more than 400 kindergarten and 800 primary students.

When the Yellow River burst its banks in 2008, Elion donated land that had been planned for development of Radix (*Isatis tinctoria L.*) to build a new town (Tara) to accommodate displaced pastoralists. Elion invested over $285 million and with government support constructed 200 hectares of desert villages, helped 36 pastoralists familiessettle, and for each household provided a house of 106 m^2 equipped with services of electricity, water, roads, and satellite receivers. The Department of Ecological Projects of Elion assisted in the mobilization of local farmers and pastoralists, provided them with technical support on production and ecological restoration to generate income, and helped them transition from a traditional to a modern lifestyle. For pastoralists who remained, ecological education was provided in germplasm and "fenced grazing". Infrastructure investments were also made, including the Yellow River Bridge and paved roads across the desert.

Over 100,000 farmers and pastoralists have, through various means, been one of the largest beneficiaries of the Kubuqi project's green economy. These include: renting desert land to the enterprise and becoming shareholders; developing desert national tourism and becoming tourist property owners; planting trees, grass, and herbs to provide small businesses or work; and farming activities, such as planting vegetables and fruits, or raising cattle and sheep. Farm produce supplies meat, eggs, poultry, milk, and green organic food to enterprises and tourism.

The huge investments in desertification control and ecological reconstruction have resulted in much hiring of labour and Elion has conducted over one million person days of training of ecological reconstruction workers in Ordos. Over 200 teams have been organized to participate in the ecological restoration industry all over China. Strong community relations have also been important, for example through the Workers Cooperative Team, which organized migrant workers to carry out annual seasonal tree and grass planting. These arrangements include both commissioning on a commercial contractual basis and through partnerships in ecological management. The company has also hired sand station experts from the Forestry Department to provide detailed technical guidance for the Workers Team.

Elion's leadership has provided an example for others to participate in Kubuqi restoration and governance. The company has catalysed and inspired collective action by local farmers, the community and private companies in desert ecological restoration, with national and global impacts (e.g., through the United Nations). Private companies now finance 90% of the afforestation in Ordos and Elion's investment has become minor. Inner Mongolia Autonomous Region has more than 2,000 enterprises financing forestry, responsible for 90% of afforestation tasks.

6.3.2 Partnerships among enterprises and with other groups

Despite its humble beginnings in the isolated Kubuqi area, Elion has gone on to successively incorporate several large- and medium-sized state-owned and private enterprises, including Shenhua, Huayi, Shanneng, Jidong, Huiyuan, Fanhai, Wanda, and Mengcao. Learning from the type of business thinking that drove the development of the Internet, Elion applies financing models from the innovation industry to attract investment, adopting an open-ended property model of the *Minority Equities Programs Package.* At the same time, based on the *All-Sharing* concept, the company is trying to innovate its business model by means of co-funding, co-contracting projects, and co-management in the hope of making Kubuqi into a desert ecological platform. Elion's vision is that joining hands with leaders in related industries will accelerate green economy thinking.

International partnerships are playing an important advocacy role. In 2014, the Elion Foundation, a china-based NGO, together with UNEP, successfully conducted the Youth Summer Camp of the Global Environment Outlook (GEO-5). This summer camp included a series of lectures themed by the GEO-5 topics and an expedition to the Kubuqi Project. The Camp aims to instil in the youth the seriousness of global environment challenges.

Partnerships with scientific research institutions have been key to the project's technological advances in desert restoration (see Section 4) including its germplasm bank of desert plants. Elion has developed its own desert research institute, which liaises with experts in local colleges and universities in Inner Mongolia Autonomous Region. In addition, Elion has set up the International Ecologists Union, which is composed of experts in ecosystem management from 57 countries all over the world, for example involving specialists and scholars from the Israel Academy of Agricultural Sciences (ARO), Ben-

Gurion University of the Negev, China Agricultural University, Beijing Forestry University, the Desert Research Institute of the Chinese Academy of Sciences, the Xinjiang Ecological Geography Research Institute of the Chinese Academy of Sciences, the Inner Mongolia Autonomous Region Agricultural University, and the Chinese Academy of Forestry Sciences. This union has helped build a scientific and technological network for global desert research.

Overall the Kubuqi approach of scientific partnership, collaboration between various social actors, supported by nested legal structures in support of desertification, implements the major principles for successful science-driven institutional change in desertification control proposed by Yang and Li (2015) based on a study in northern China (Table 6.1). They concluded that strong rules result in more effective science-driven institutional changes.

Table 6.1. Three major principles and nine working principles for successful science-driven institutional change in desertification control (Yang and Li 2015).

Major Principle I

There are collaborative, effective, and sustainable applications and extensions of advanced scientific methods for desertification control.

1. Biological controls provide major technical support for combating desertification.
2. Agricultural controls provide technical supplements to biological and other technologies.
3. There is effective synergy among different types of scientific methods for desertification control.

Major Principle II

There is effective collaboration among various social actors and organizations.

4. Government is a primary participant that guides programs for combating desertification and setting enabling institutional arrangements and incentives to encourage participation of all stakeholders, but does not suppress the participation of other social actors and organizations.
5. Other social actors and organizations, such as farmers (or herders), families, communities and scholars, participate in desertification control and play an effective role.
6. There are coordination, communication and conflict-resolution mechanisms among the various social actors.

Major Principle III

There are localized, collaborative and nested laws, regulations and rules regarding desertification control.

7. There are localized, collaborative and nested laws and regulations regarding desertification control.
8. There are localized, collaborative and nested operation mechanisms for laws and regulations regarding desertification control.
9. There are localized, collaborative and nested rules and methods for desertification control.

PART 2 PROJECT APPRAISAL

Part 2 provides an appraisal of the impacts and sustainability of the project, summarized in the form of an economic risk-return model. First the modelling methods are described. Next on-site and off-site environmental impacts and risks are summarized before describing the modelling results. Conclusions are drawn from this evidence on the overall sustainability of the project, critical success factors and considerations for scaling out desert green economy.

7 Modelling methods

Applied Information Economics (AIE) was used in this study to capture the uncertainty in the available information on the costs, benefits and risks associated with the Kubuqi Project over time. There is much expert local knowledge available and the challenge for this review was how to systematically capture evidence from both expert knowledge and fragmented data from various sources. Due to the limited time available for this study, there was also a need to focus evidence-collection on areas that would provide most insight into the outcomes of the project.

Bayesian decision analytic methods and value of information analysis provide a framework for dealing with this type of problem. With this approach, evidence is represented in the form of probability distributions, as opposed to average values, which allows expert knowledge and data to be combined and the uncertainty in this information to be captured. Bayesian analysis propagates the uncertainties through the analysis, thereby presenting a realistic picture of the uncertainty in the current state of knowledge and its implications for project outcomes. The Bayesian framework provides for updating of the probability distributions in the light of new evidence. In addition, capturing uncertainties allows the calculation of value of information, which points to where further information collection will have most value for improving the analysis. AIE is an implementation of the Bayesian approach (Hubbard 2014). It is a method for modelling decisions and making measurements for complex and highly uncertain problems. AIE is a synthesis of techniques from economics, actuarial science, and other mathematical methods (Figure 7.1).

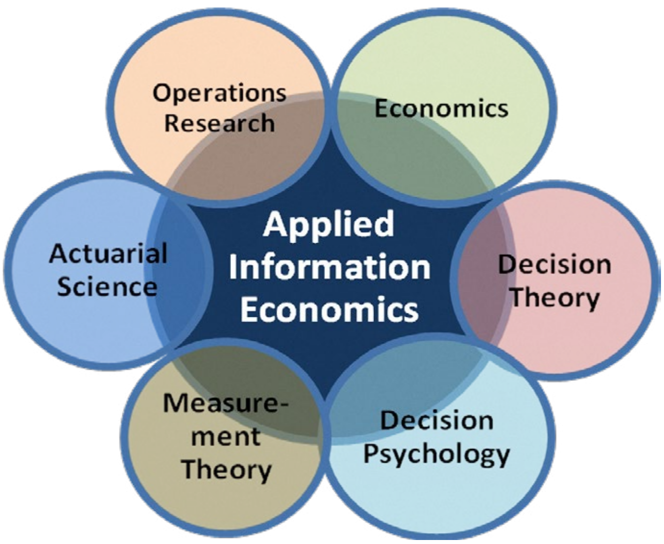


Figure 7.1. Major components of Applied Information Economics

The steps in the AIE method may be summarized as:

- **Define the Decision(s):** The first step of the method involves clarifying the real decision and identifying costs, benefits, timing, risks, and even external factors. As obvious as this step may first appear, it is the key to better understanding what to measure, and real decisions are often different from what they first appear to be. For the Kubuqi Desert analysis, the main concerns are over the sustainability of the project in terms of green economy and the decision can be framed in terms of whether to pursue agricultural profit within the project area, whether to export this model of greening the desert to other locations, or to expand the project area at the Kubuqi location.
- **Model What We Know Now:** Cost estimates, market forecasts, project risks, and other variables in a typical big investment decision are almost never known exactly. Usually, the uncertainty about some variables, especially long term forecasts, can seem extreme. Instead of choosing some arbitrary number as a point estimate, AIE focuses on determining the range of possible values for a given variable and ascribing probabilities to them. AIE uses methods to compensate for the natural overconfidence and the inconsistency of most experts and managers in estimating probability distributions. Decades of research show that experts tend to be overconfident but can be trained to express uncertainties as subjective "probability distributions" in a way that is reliable and demonstrates measurable improvement in forecasts and decisions (Hubbard 2014; Lichtenstein *et al.* 1982; Kahneman and Traversky 1972, 1973; Kahneman *et al.* 1982). These ranges are then used in a "Monte Carlo" simulation - the generating of thousands of random scenarios on a computer - to develop a profile of the likelihood of each possible outcome. Usually, this method will show that there is at least some risk of a negative outcome – and this risk will be measured.
- **Compute the Value of Additional Information:** Not all variables in a decision are worth measuring and those found to be worth measuring are often a surprise to the decision maker. How do you decide whether to focus on the depth of the water table under the Kubuqi Project area or the total water needs of the commercially grown crops in the project area? It turns out that one of those variables is much more important to the investment decision than the other, but the only way to accurately assess this is to calculate the information value. There is a tendency for managers to focus their measurement effort on variables that have little or no information value for improving decisions – a phenomenon so consistent that it has a name "the measurement inversion" (Hubbard 2014). With AIE, every variable in a model will have a computed information value that allows identification of high value variables in a decision. This approach targets only the variables in a decision that are the most likely to significantly reduce overall uncertainty in the decision.
- **Measure What Matters:** The information values guide where additional effort should be applied to reduce uncertainty. Even in situations where time and resources for more measurements are limited, significant uncertainties can be reduced. It may seem counter-intuitive, but the mathematics show that even a small amount of data can provide a significant uncertainty reduction, especially in those situations where uncertainty is high. Consequently, the variables with the highest information values are often the easiest to measure.

> ***The Measurement Inversion:*** *A pervasive phenomenon of choosing measurements that are statistically unlikely to improve decisions while ignoring higher-value measurements.*

- **Make Better Decisions:** The output of the decision model, updated with targeted measurements, is compared to the risk preferences of the organization. Research shows that the actual risk aversion level of managers often changes frequently and unconsciously. Different levels of risk tolerance are applied to different investments even when management believes they are being consistent (Brunswick 1955; Kahneman and Tversky 1972, 1973; Camerer 1981; Kahneman *et al.* 1982; Karelaia and Hogarth 2008). AIE addresses this major source of decision error by quantifying and documenting risk preferences so that analysis results can be assessed in a controlled, uniform manner.

In summary, AIE is an approach that explicitly expresses expert uncertainty as probabilities, targets measurements where they matter most, and expresses risk quantitatively.

Figure 7.2 below shows how all of the steps come together in an iterative process where measurements update uncertainty, and ultimately provide guidance for an optimized decision.

The model is built through a series of consultation workshops with subject matter experts, who also receive training and calibration in subjective probability estimation. Probability ranges for each uncertain variable are elicited from the experts or using readily available data, including from the literature. Further details of the modelling procedure and modelling results are given in Section 10.

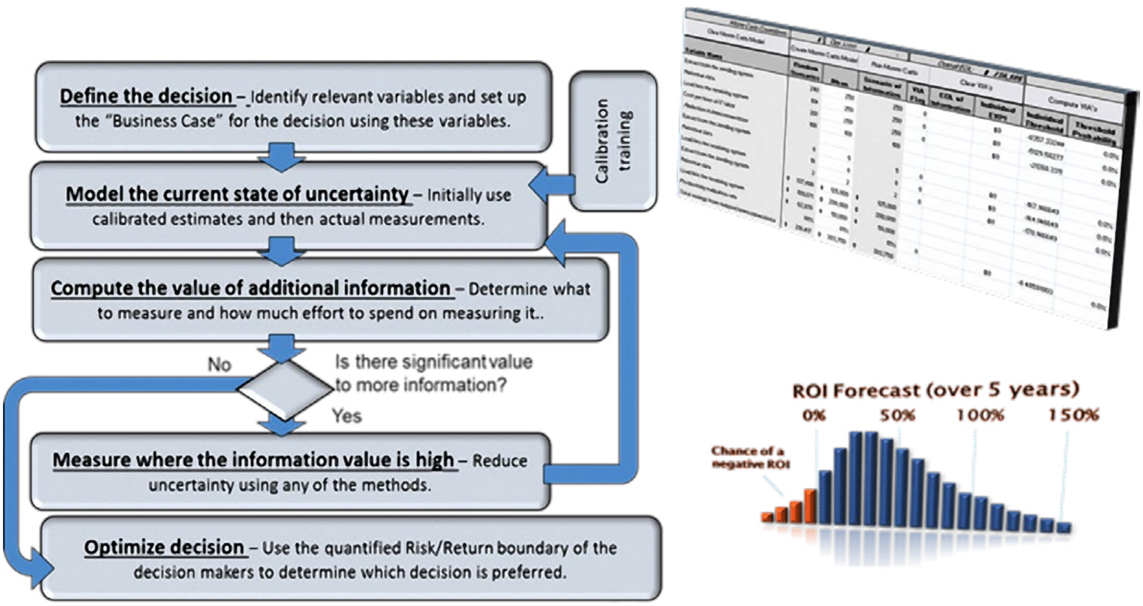


Figure 7.2. The five step process for a probabilistic risk-return analysis using Applied Information Economics.

8 Environmental impacts

A number of economic and social benefits of the Kubuqi project, such as improved education and housing, improved employment opportunities, and intensification and increased profitability of farming activities, have been described in Part 1. This chapter summarizes evidence on on-site and off-site environmental impacts of the project, which formed a basis for input to the economic model.

8.1 On-site environmental impacts

8.1.1 Wind and sand movement

The effectiveness of shelterbelts in reducing wind speed and sand movement in China desert environments is well documented (Cao 1983; Chepil 1949; Chepil and Woodruf 1963; Wilske *et al.* 2009). For example Chepil (1949) reported that shelter belts of poplar and willow on sandy alluvial soils in northern China, of 120 m long and 18 m wide planted along field edges, provided almost complete protection of crops. He reported a 50% reduction in wind speed at a height of 30 cm above ground level is required to be completely effective. This condition was met for a single row willow belt for a distance of up to 6 to 7 times the height of the trees.

The vegetation aerial cover within the Kubuqi belt has reached up to a level of 65% to 70% with reported average benefits of 30% wind reduction at 20 cm above the ground surface (Elion unpubl.). The measurement of wind speed at four heights (0.2 m, 0.5 m, 1 m and 2 m) adjacent to the forest belt showed lower average wind speeds than the control wind speeds, with the greatest reduction in wind speed relative to the control of 61% at 0.2 m height, and 45% above a height of 0.5 m. At 20 cm height, the wind prevention efficiency for different shrubs is reported as: *Hedysarum scoparium,* 74%; *Hippophae rhamnoides,* 58%; *Caragana microphylla,* 28%; and *Tamarix chinensis,* 22% (Elion unpubl.). The shelterbelt has helped to improved the local ecological environment, reducing wind and aeolian sand movement into the Yellow River (Figure 4.8) and protecting infrastructure (Figure 8.1).

8.1.2 Soil health

Shelterbelts in the project area have reportedly improved soil physical and chemical characteristics, including lower pH and electrical conductivity values, and increased contents of soil organic matter, available nitrogen, phosphorus, and potassium compared to control sites. Evidence from published articles in the international scientific literature supports Elion's observations of improved soil conditions under the trees in this environment. For example Su and Zhao (2003) studied soil properties at 0 to 5 cm and 5 to 20 cm depths under age sequences of 0, 5, 13, 21, and 28 year-old *Caragana microphylla,* plantations in the semi-arid Horqin sandy land of north China. Results showed that shrub establishment and development improved soil water holding capacity, enhanced organic C and total N accumulation, and decreased pH and bulk density. Carbon and nitrogen concentrations increased significantly with increasing plantation age and had increased by 10 to 20 times in 28-year-old plantations compared with non-vegetated dunes. Incremental rates of improvement were faster in the early establishment stage (0 -13 years) than late successional stage (13 - 28 years). The C and N contents were higher under the plant canopies as compared with alleys, but with increased plantation age the 'islands of fertility' expanded. At the same time, *Caragana* facilitated the colonization and development of herbaceous species by improving the microclimate.

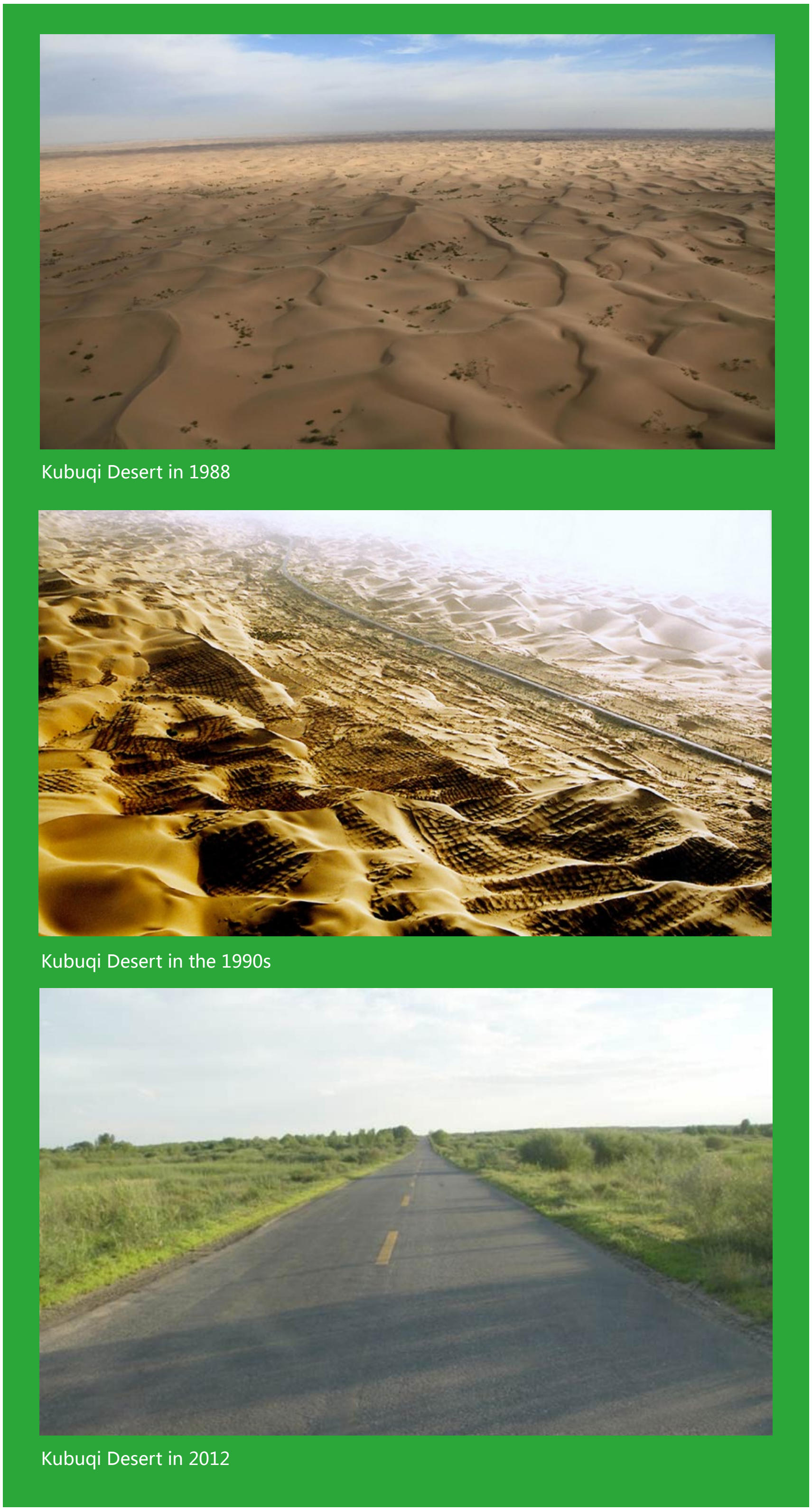


Figure 8.1. Transition in greening and stabilization of the desert in the Kubuqi Project: (top) original state in 1988, (middle) highway protected by shelterbelt and chequerboard plantation, (bottom) green stable state of highway in 2012.

8.1.3 Hydrological impacts

Aridity (annual potential evapotranspiration divided by annual precipitation) ranges from 3.23 to 7.31, indicating that actual land surface evapotranspiration is limited by available water rather than solar energy. The annual potential evapotranspiration (1985-2009) was 1,242 mm, using pan evaporation data from Hangjin Qi MET station, corrected using a coefficient for a short green crop. The average annual precipitation (1985-2009) varied from 385 mm to 170 mm (Yin 2011) from east to west across the Kubuqi Desert project area.

Rainfall in the region is generally not enough to maintain the growth of trees without supplementation either by irrigation or groundwater. When reliant on rainfall alone, trees left to become large (e.g., 10 to 20 years after planting) will eventually dry out soils, growth will slow and trees may die. In the Kubuqi Project successful tree planting has been confined to the riparian zone of rivers or lakes and low-lying lands where the groundwater table is close to the land surface. In other areas xerophytic shrubs and herbs are grown on local precipitation alone. Generally though, vegetation restoration at a large scale will increase regional transpiration and impact on the regional water balance.

When considering hydrological impact analysis, it is important to determine actual evapotranspiration. However, because the area is not a closed watershed, it is difficult to evaluate the actual water consumption by vegetation without data on potential evapotranspiration, surface flow and groundwater table levels. Here, simple estimation was done as follows. First, potential evapotranspiration over the project area was calculated from meteorological data using the Takahashi (1979) formula. Second, the amount of irrigation water used was estimated from field survey data. Third, evaporation from open water surfaces was estimated using the area of water bodies and the potential evaporation rate. The sum of these three values was taken as a first approximation of the regional actual evapotranspiration.

Using Takahashi's equation (Equation 5.1), the average annual potential evapotranspiration in the Kubuqi Desert Project area was estimated at 223 mm, varying interannually from 100 mm to 322 mm, based on monthly precipitation and temperature data from Hangjin Qi meteorological station from 1959 to 2013. The potential evapotranspiration fluctuated inter-annually but there is no clear trend over the past 54 years (Figure 8.2). The estimated maximum evapotranspiration occurred in July and the evapotranspiration during the growing season from April to October was estimated to account for 94% of the annual total (Figure 8.3).

Equation 5.1

$$E_a = \frac{3100 P_M}{3100 + 1.8 P_M^2 \exp\left(-\frac{43.4 T_M}{235.0 + T_M}\right)}$$

Where:

E_a is actual evapotranspiration from the regional land surface in mm,

P_M is average monthly precipitation in mm.

T_M is average monthly air temperature in °C.

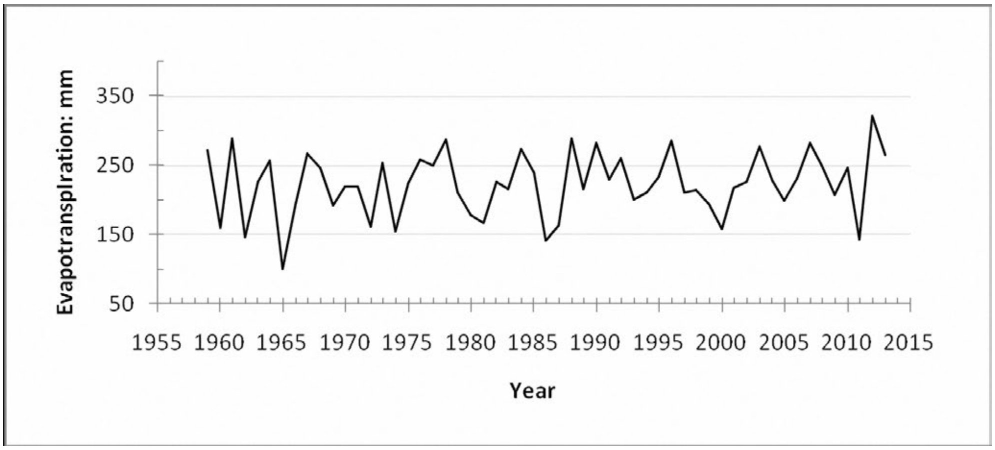


Figure 8.2. Estimated annual evapotranspiration based on precipitation and temperature data, from 1959 to 2013 in the Kubuqi Project area.

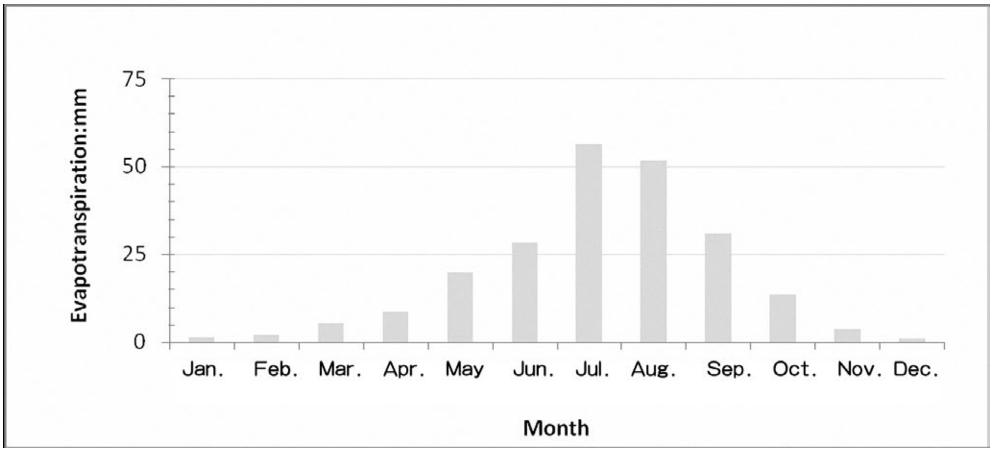


Figure 8.3. Average monthly actual evapotranspiration in the Kubuqi Project area.

However, the Takahashi equation assumes evaporation is affected by precipitation and temperature, and does not consider evaporation from external water sources, such as irrigation water and surface water. Thus, Takahashi's equation could underestimate the true total evaporation. Therefore irrigation water use was calculated and total water use by vegetation was also included in the model described in Section 10.

In order to derive relatively reliable water consumption data, we needed to estimate the average irrigation water used by tree planting practices. The tree planting and irrigation practices are shown in Rows 1 to 5 in Table 8.1. The estimated total irrigation water for the project area during the whole project period amounted to 38.5 million m^3 over a sand fixing afforestation area of 5,870 km^2. The open surface water body evaporated 4.97 million m^3 of water, calculated by using the potential evapotranspiration rate and the water body area (4 km^2). Most tree plantings only need to be watered during the first one or two years after planting. Thus, the annual irrigation water consumption was 2.17 *106 m^3, estimated as a simple arithmetic mean of the total period water consumption over the afforestation area considering the successive irrigations. The total annual external water consumption beyond rainfall over the project area was calculated to amount to 7.14 million m^3, equivalent to 1.2 mm water depth per year, which is a small amount (between 0.3% and 0.7%) when expressed as a proportion of the total annual rainfall.

Wilske et al. (2009) estimated a poplar plantation in Kubuqi elevated growing season ET by 2% and the ET/precipitation ratio from 1.0 to 1.5 as compared to natural shrubland. They concluded that this change in the water balance would only be sustained if trees had access to groundwater, either by irrigation or with roots tapping groundwater. These authors concluded that dense plantings of poplar trees could cause decreasing water tables and increasing water stress at regional scales. Hydrological risks are considered further in Sections 9.1 and 10.

Table 8.1. External water demand estimation of ecological restoration project area

	Sand fixing afforestation and irrigation practice					Open water surfaces area (lakes)
1	Species	*Populus spp* *Elaeagnus angustifolia* *Pinus sylvestris*	*Haloxylon ammodendron* *Astragalus adsurgens* Pall.	Liquorice	*Caragana intermedi* Kuang & H.C. Fu *Salix psammophila* *Hedysarum scoparium* *Hedysarum mongolicum* Turcz.	
2	Area (km^2)	3,200	200	1,133	1,333	4
3	Planting density (plants ha^{-1})	200	-	-	-	
4	Irrigation method	Drip irrigation 14 times per year in first 2 or 3 years after planting	Drip and spray irrigation only at planting	Spray irrigation at planting and once more in a year	No irrigation	
5	Watering amount per irrigation event	10 l/stand	12 l/m^2	12 l/m^2		

6	Total irrigation amount (10^6 m^3) for the whole project period	8.96 =(3200*100 *200 *10 *14/1000)	2.4 =(200*12/ 1000)	27.192 =(1133*12 *2/1000)		4.968 =(4*1242 /100)
7	Annual irrigation amount (10^6 m^3)	1.034 =(8.96/26*3)	0.092 =(2.4/26)	1.046 =(27.192/ 26)		4.968
8	Sum of external annual water demand (10^6 m^3)	2.172			0	4.968

8.2 Off-site environmental impacts

8.2.1 Dust storms

One of the greatest perceived benefits of the Kubuqi Project is reduction in frequency and severity of dust storms. There is evidence from a recent study of time trends in vegetation index in the Green Great Wall region, which begun in 1978, that the Green Great Wall has greatly improved the vegetation index and effectively reduced dust storm intensity in northern China compared with adjacent regions (Tan and Li 2015). The study analysed time trends in Normalized Vegetation Difference Index (NDVI), a measure of green vegetation cover from satellite imagery, together with rainfall and dust storm data from weather stations. An index of dust storm intensity was developed that includes frequency, visibility, and duration of dust events. The effects of climatic change and human pressure were discounted in the study. It was found that NDVI was not related to rainfall trends and dust storm intensity decreased in response to increased NDVI. The Kubuqi Project area displays a consistent greening trend that could have caused a decrease in dust storms (Figure 8.4). This is supported by evidence from the meteorological records at Hangjin Qi, which indicated that the number of sandstorm days per year decreased dramatically after the 1970s. Although the decreasing trend was evident before the Kubuqi Project started it has continued until now. No evidence could be found on whether the Kubuqi Project has an impact on reducing dust storms in Beijing.

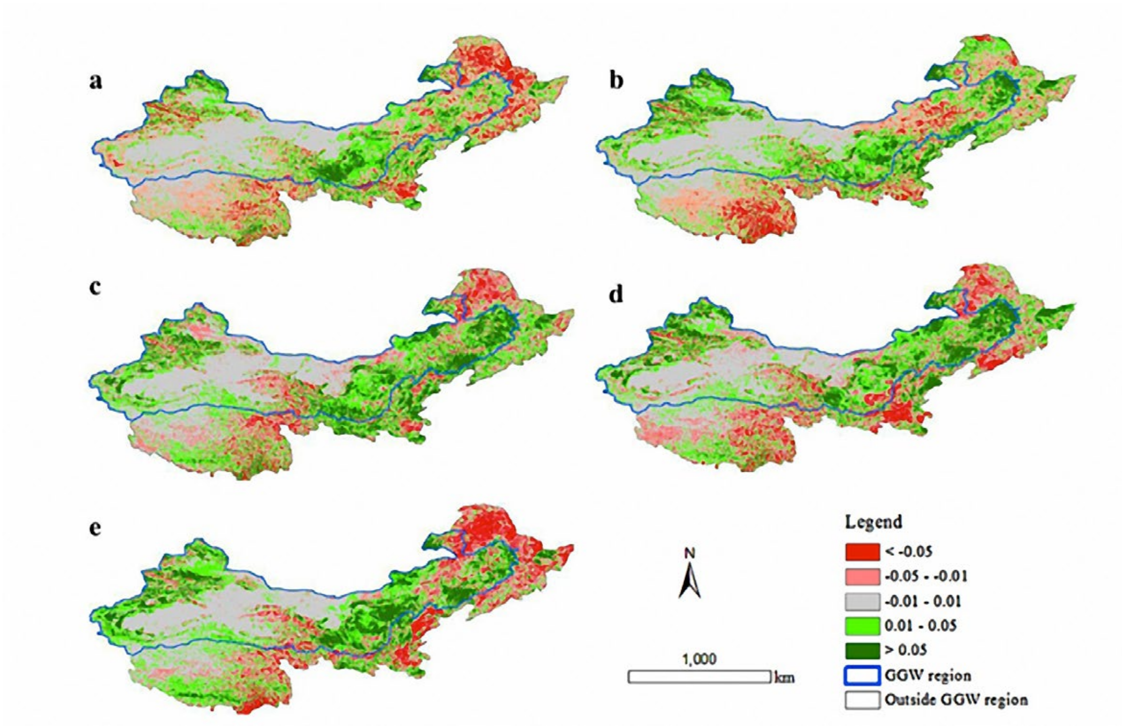


Figure 8.4. Changes in the average summer NDVI values over different periods: (a) between 1981–1983 and 1984–1986; (b) between 1981–1983 and 1987–1989; (c) between 1981–1983 and 1990–1992; (d) between 1981–1983 and 1993–1995; (e) between 1981–1983 and 1996–1998. Source: Tan and Li 2015[8].

8.2.2 Biodiversity

With the emergence of over 5,000 km^2 of oasis, the biodiversity in Kubuqi Desert has been restored gradually. The ecological environment of several lakes in Kubuqi Desert has apparently been remarkably improved (Figure 8.5) and the Swan Lake, 35 km east of Bayanhaote town, has become a wetland habitat for migratory swans (Elion, unpubl). However there are no project observations on water table height and changes in the project area, and there are no available data to support comment on the causes of the restoration of the lake hydrology.

General reclamation efforts are reported to have increased plant diversity compared with before the formation of the People's Republic of China (1949). According to a 2012 survey (Elion unpubl.), Kubuqi has 374 species of wild plants, including 309 kinds of forage plants and 139 kinds of medicinal plants, but it was not possible to make comparisons against the 1949 baseline.

The artificial planting of medicinal plants, aromatic plants, oil plants, fibre plants, pesticide plants, and nectar plants for production purposes has also contributed to an increase in biodiversity. Forage plant species in natural pastures have also increased significantly, for example, the composite family has 23 genera and 41 species, the grass family has 18 genera and 25 species; and the bean or pea family has 12 genera and 32 species. The project has also conserved 160,000 ha of wild liquorice (Elion unpubl.).

[8] This image was published in Tan and Li 2015, copyright Elsevier.

Figure 8.5. Lakes in the Kubuqi Project area.

Wildlife diversity in the region is reported to have increased. Wild mammals mostly appear in hilly areas and deserts. Local experts report that there are increasing sightings of species that had all but disappeared, including wolves, Mongolian gazelles, foxes, badgers, hares, hedgehogs, mice, voles, and jerboa (desert rodents). Wild birds, amphibians and arthropods are now reported across the whole desert. Common wild birds now include pheasants, hawks, owls, crows, magpies, sparrows, pigeons, snipe, wild geese, wild swallows, teals, quails, larks, sand grouse, rock partridges, cuckoos, woodpeckers, semi-crows, grass chicken, Hoopoe, wild ducks, wild pigeons, and thrushes.

8.2.3 Climate and soils

Local experts report that rainfall has increased in the project area as a result of greening but this could not be substantiated from meteorological records from Hangjin Qi (see Section 3.2.2) over the past 50 years, although temperature has increased. Weather stations would need to be situated at different locations in the project area to establish local and microclimatic impacts of reduced wind speeds, improved soil conditions and altered evapotranspiration regimes. Increased transpiration from denser tree cover can result in changes in local precipitation (so called rainbow water; Keys *et al.* 2012). One

Figure 8.6. Migratory swans in the Kubuqi Project lakes and other birdlife.

would expect most rainfall that is not transpired would be evaporated in this dry climate, however additional water available from irrigation or groundwater would increase transpiration.

An assessment of the cumulative carbon sequestration of the Kubuqi Project estimated that afforestation of 5,153 km^2 from 1998 to 2012 has sequestered a total of 49,140 t CO_2 (GEP report).

Elion does not use commercial mineral fertilizer or pesticides and so there is no environmental risk from these sources.

9 Risks

9.1 Hydrological risks

Hydrological risk here refers broadly to the situation when water use exceeds the carrying capacity or water renewability in a region. Planting activities of the Kubuqi Desert restoration project consumes water that can come from precipitation, surface or groundwater. If the additional growth of vegetation transpires water that would otherwise have been lost by evaporation from the soil surface, and water used for supplementary irrigation is not greater than the replenishment rate of the water source, then the system is sustainable. Water overuse would be expected to reduce groundwater table levels. The level of the groundwater table was therefore adopted as an indicator for risk analysis in the model (Section 10).

In the absence of any measurements of the groundwater table level, local inhabitants were interviewed. According to them the groundwater table has slightly dropped in places where the groundwater table was close to the surface. The water table apparently dropped from 0.5 to 1.0 m below the land surface before the project to a depth of 1.0 to 3.0 m today. The maximum decline of water table is about 3 m, with an average annual rate of decrease of 0.1 m. As expected, planting activities do appear to have increased water use in the area. If the groundwater table continues to drop, the hydrological sustainability would be threatened. This risk is analysed further in the modelling section.

The irrigation water for afforestation activities comes from the confined aquifer, 80 to 120 m beneath the land surface (Elion unpubl.). Because the groundwater comes from a deep confined aquifer, it has no direct relationship with the groundwater water table changes due to water use by the trees (whose roots do not reach these depths) and is sustainable if the pumping amount is less than the recharge amount.

We estimated water demand for future afforestation activities. The Kubuqi Project map (Figure 4.10) shows the location of the plantations inside the Hangjin Qi. Areas already forested coincide with areas with good water resources. Afforestation began from the South and North ends of the Desert, and areas around the lowland lakes (Haizi), which are rich in groundwater. In these areas there is a water surplus according to water demand and supply planning estimates (Inner Mongolia Autonomous Region 2005). For example, Yihewusussumu County and Bayannaoer County have a water surplus of more than 40 million m^3. Expansion of future plantations into areas with less favourable water resources are likely to be slowed down by limitations on water availability and increased planting costs per unit area. From interviews with local mangers, hydrological related costs, including the disposable input of irrigation facilities and their costs of operation and maintenance, are currently about $1,500/ha/yr for irrigated sand fixing afforestation.

Assuming that the irrigated tree planting areas will increase by 1,000 km^2 in the next 10 years, the annual irrigation water requirement will increase by 2.4 million m^3. The whole project area irrigation water demand will increase from the current demand 7.14 million m^3 to 9.54 million m^3, assuming no change in climate. Compared with an available water supply of 40 million m^3, the hydrological risk of tree planting activities in terms of irrigation requirement in the near future seems to be low. However this analysis does not consider other water uses and demands over the next 10 years. For example water demands from cities upstream may increase demand, which could reduce groundwater recharge from the Yellow River in the project area. A more reliable risk analysis would require a more complex model to include multiple water uses and priorities at a regional scale.The impact of large trees, such as poplar and pine, on water uptake from groundwater is considered in the model described in Section 10. In terms of water quality, local experts consider the risk of decline in water quality, for example through increased salinity, to be low with the current irrigation practices and quality of water sources.

9.2 Other risks

Increased soil salinity or alkalinity does certainly pose a potential risk as saline-alkaline soils naturally occur in the area. Salinity due to rising groundwater in low lying areas, or salt accumulation in top-soils of irrigated areas due to high evaporation rates pose potential risks. However to date there is no evidence for any of these risks being realized.

No plant pest/disease outbreaks were reported by Elion and perhaps the cold winters coupled with hot summers with limited rainfall help to suppress pests and diseases. The strategy of steadily increasing the diversity of plant species grown also helps to mitigate this risk.

Attention should also be paid to maintaining within species genetic diversity, especially for crops on which the pharmaceutical industry is heavily dependent (e.g. liquorice).

The climate records do not indicate widely fluctuating precipitation but the steady increase in temperature could increase evaporation rates and water demand, or limit growth of some species. However short-term climatic variability, beyond variable demand for irrigation, does not appear to be a significant risk.

The Yellow River Basin is susceptible to climate change, especially as it is fed from snowmelt from the Tibetan Plateau, which is sensitive to long-term temperature increases. Climate change model projections for 2001 to 2030 (Wu *et al.* 2015), using the RegCM3 high-resolution regional climate model, indicated a decrease in annual run-off of 11.6% for the whole basin and 8.0% for the interflow basin where the project is located. Soil moisture is projected to decrease by 2.7% in the project area. However a study by Xu *et al. (*2015), which included a Yellow River catchment, concluded that reporting of climate change impacts on rivers in terms of mean annual flows masks the magnitude of uncertainty in flows that are of most importance to water management. Their study showed that the greatest source of uncertainty in hydrological projections is the choice of Global Circulation Model.

Other risks include changes in the prices of the commodities grown and how this can change the inflation-adjusted revenue from crops in the future. This uncertainty also creates a risk that changes in prices will incentivise a change in the future share of various crops grown and that this may lead to a higher share of the land being used for more water intensive crops.

Energy prices are also an uncertainty that will affect the costs of energy-related inputs to the desert such as pumping costs, especially from lower depths if the water table lowers significantly. Wage uncertainties are a factor including uncertainties about competing sources of labour. However, higher local wages, while treated as a cost for the project, are also an objective of the project. The key risk related to wages is that, over the long run, a high level of agricultural output will strain the water table and this will impact agricultural revenue.

The slow down of China's economy, and of the Ordos economy in particular, may affect the Kubuqi Project as central and local government provide financial and political incentives to the investors in green development, including Elion. However this may be countered by on-going reforms in governance systems, which aim to further develop concepts of green economy (also called eco-civilization).

10 The model

The model of the Kubuqi Desert Green Economy Project was generated using the previously described AIE process (Section 7). The model resides in a tool based on Excel macros which generate the random scenarios for the Monte Carlo simulation and which compute the value of information. This section of the report will describe:

1. Model development
2. Basic structure of the impact pathway in the model
3. Estimation process
4. Information value calculations and subsequent reductions of uncertainty
5. Final results and recommendations.

10.1 Model development

The scope and nature of the quantitative analysis was initially outlined during on-site meetings in September 2014. Using the spreadsheet tool developed by Hubbard Decision Research, the model was then developed in detail in a series of remotely conducted workshops with the Subject Matter Experts (SMEs) to define variables and make probability estimations for the hydrology and community forestry components of the model. Estimation worksheets were provided to SMEs for gathering estimates of yield, water requirements and other data for each plant species.The initial model was populated with estimates for every variable. The value of information analysis (VIA) and final risk/return analysis was then computed using the Hubbard Decision Research spreadsheet tools.

As discussed in the methodology section, Applied Information Economics uses a cost benefit analysis as the basic template for models. The cost benefit analysis is divided primarily into an Inputs page (Appendix 2) and a Cash Flow page (Appendix 3). The variables on the Inputs page feed into logic that is constructed in the Cash Flow page.

The model consists of six main sections containing 100 independent variables. The logic connecting the input estimates to calculations of income and net present value is constructed on a partnered sheet referred to as a “Cash Flow” that has five sections containing rows of calculations over 50 years (each year is a separate column). Most of the rows on the Cash Flow are used to calculate costs and revenues associated with the agricultural aspect of the Kubuqi Project including water table dynamics. More details follow in the “Model Components” section.

For each of the variables on the Inputs page, ranges for the values are collected based on estimations from SMEs – “arms-length data”, i.e., data that are easily accessible. Data that would require more effort to gather and analyze would be considered only after the information value calculations justified the effort.

Using ranges for our inputs allows the modeller to capture more elements of the investment dilemma resulting in a more realistic analysis. A good example of this advantage is the calculation of benefits related to the reduced frequency of sand storms in the Kubuqi Project area. While some data exists related to the historical cost of these sandstorms (such as the quantity of sand removed annually from the Yellow River), many of the variables such as “increase in tourism and eco-tourism” or “increase in housing value due to decreased sandstorms” were not connected to any arms-length data. Just leaving out these benefits would be equivalent to assigning them a benefit of zero, which is obviously not correct. Capturing these variables with a wide range lets the user include them in the analysis with a realistic level of current certainty. Whether these estimates need to be further investigated is then determined by the value of information calculations (as explained in Section 7).

10.2 Basic Structure of the Impact Pathway

There are nine major components in the model – six appear in the Inputs section and all nine are contained in the Cash Flow section. The six sections in the Inputs section are as follows:

1. Economic Environment
2. Water Budget
3. Irrigation
4. Properties of Plant Species
5. Initial Investments
6. Non-Agricultural Benefits

These six sections have analogous components in the 50-year forecast Cash Flow section as well as three additional components:

7. Direct Agricultural Income
8. Net Income per Capita
9. Total Return

The relationship of each of these sections in shown in Figure 10.1. The details further describing each section follow.

10.2.1 Water Budget

The water budget component of the model contains variables having to do with precipitation, the water table, and water uses. This includes variables such as the average rainfall, the area of the water table, rates of infiltration, rates of evaporation, and plant water uptake and requirements. We allow for a trend in precipitation, but do not model precipitation changes due to the greening itself.

This component addresses issues regarding total projected water use from the water table, and the probability that the water table is depleted by a given amount. In Monte Carlo simulations, the Cash Flow includes a randomized future path of precipitation based on standard deviation and averages derived from historical data. The Cash Flow also tracks changes in the water table and provides the inputs for calculating irrigation needs and costs.

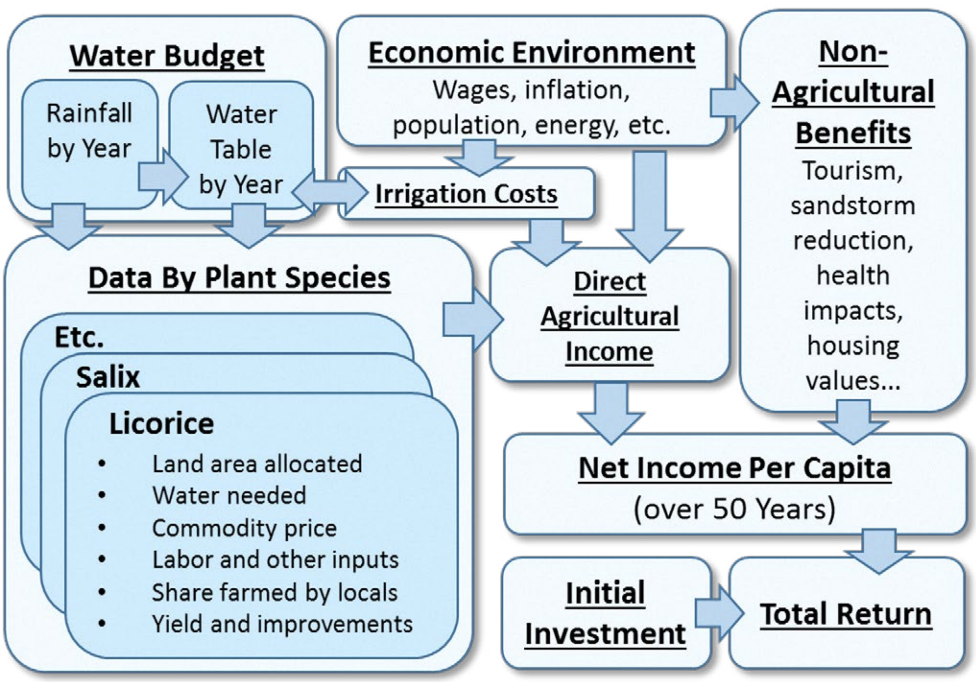


Figure 10.1. Kubuqi Project model impact pathways.

The possibility exists that changes in runoff, evaporation, and transpiration rates due specifically to the greening would be significant enough to change average precipitation, but feedback from the SMEs indicated this was not probable in the Kubuqi Project area. As a result, a highly simplified representation of hydrology was developed. For instance, the water budget is estimated for the whole land area for a whole year – so the model does not detail rainfall by season or rain event. Factors such as topology and interaction with the Yellow River were only captured in the wide ranges used for initial water table area, depth, and thickness, as well as wide ranges on the usability and usage of water.

10.2.2 Irrigation

Irrigation could be considered a subsection of the Water Budget but was broken out because of its potential importance on model results. Irrigation was first modelled as a static quantity per hectare depending on plant type. Subsequently, irrigation was modelled as a dynamic quantity depending on annual precipitation – total plant water needs were provided as an estimate, and the percentage provided by irrigation was dependent on precipitation levels. In rainy years, irrigation might be low or zero whereas in dry years irrigation might supply the majority of the plant water needs. In the most recent version of the model, plant water needs were decomposed and estimated at the species level. Irrigation costs were dependent on usage, water table levels, and estimates of drilling and required maintenance. Literature review fundamentally changed how the water requirements were modelled, which reduced uncertainty, but as is shown in the following sections, there are reasons to think that further uncertainty reduction is merited.

10.2.3 Data by Plant Species

Data by plant species included 8 categories of crops:

1. Liquorice
2. Pine and Poplar
3. Vegetables
4. *Salix psammophila*
5. *Caragana microphylla*
6. *Hedysarum scoparium*
7. *Haloxylon ammondendron*
8. Grasses and shrubs that are air-seeded

Each category had metrics provided by SMEs on the Inputs sheet such as total hectares, average yield, water requirements, baseline commodity price, labour inputs, and others. In each case these inputs are used on the Cash Flow and are then adjusted based on other input values. For example, the input variable "average yield" forms a baseline but the actual annual yield on the Cash Flow page would depend on stochastically generated rainfall amounts, quantity of irrigated water, and soil characteristics. As another example, the baseline commodity price is adjusted in the time series on the Cash Flow according to a randomized inflation path.

Simplifying assumptions were made on plant yield curves and their relationship to changes in water uptake and soil organic matter. Yield was modelled having a linear relationship to precipitation – however, a large range on the multiplier was used to offset this oversimplification and capture the uncertainty on the slope and nature of the relationship.

10.2.4 Economic Environment

This section of the model contains basic economic variables such as inflation rates, exchange rates, wage estimates, and population and demographic variables. Most of these estimates were based on historical data from official governmental sources.

Projections of population growth rate were based on historical trends in rural Inner Mongolia Autonomous Region over the past twenty years. If the Kubuqi Project area experiences economic expansion as a result of current activities, it would be reasonable to assume that population change in the project area would be different than other parts of rural Inner Mongolia Autonomous Region. The possibility of positive population growth in the project area was therefore included in the range of uncertainty to allow for this. Estimating the daily wage for project labour in the Kubuqi Project area was based on sources from the mid-2000s, as well as estimates of labour inflation since then. The most recent estimate is necessarily wide to reflect uncertainty embedded in these sources.

10.2.5 Direct Agricultural Income

Direct agricultural benefits include harvest of wood, harvest of crops such as vegetables and liquorice, and harvest of forage materials (often forage is derived from plant matter used primarily for its ecological purpose, such as *Salix, Caragana* and *Haloxylon*). Yields of all of these are derived from the individual plant characteristics (provided by SMEs in an estimation worksheet), from variables such as changes in precipitation (modelled in the Water Budget section) and changes in soil organic matter and composition, as well as variables such as wage and irrigation costs derived from the Economic Environment variables.

The plants are split into two basic categories: plant species whose initial purpose is ecological restoration and plants primarily grown for harvest and sale. A large part of the uncertainty in the model arose from the percentage of plants harvested for forage whose primary purpose was ecological restoration. These plants represented a large percentage of the planted hectares (80%) in the project area, and the percentage of these harvested was the variable with the second largest information value.

10.2.6 Non-Agricultural Benefits and Initial Investment

Non-agricultural benefits included estimates of the benefits derived from improvements in ecology, notably improvements having to do with reduced sandstorms. These benefits included increases in tourism, increases in housing values, decrease in costs of sand removal, and decrease in other costs of sandstorms such as health issues and productivity losses to machinery damage and shutdown.

Initial investment was initially a wide range estimate of the total cost per square kilometre of establishing the green belt in the Kubuqi Desert. Since this variable came back with a high information value, it was highlighted in the later parts of the project as a variable for reducing uncertainty through decomposition and more research.

Net Income per Capita was calculated by estimating a percentage of the direct agricultural benefit that accrues to local incomes, and adding in labour wages for agricultural and other industry, made possible by the greening of the desert. Total Return is calculated as a net present value of the initial investment in the greening the desert project and includes all the costs as well as all the agricultural and non-agricultural benefits for the next fifty years, discounted by a time preference of money.

10.3 Estimation Process

The AIE process starts by populating a model with wide range calibrated estimates. These initial estimates can be later improved in two ways:

1. **The SME directly makes a calibrated estimate.** For many of the variables in the model, subject matter experts will have significantly more knowledge and therefore the range of their uncertainty will be narrower than the initial estimates. SMEs may not make a direct estimate but still give context or information that allows the modellers to exclude parts of the initial range. This process is referred to as updating a subjective Bayesian estimate. An estimate has a wide range prior and is then updated based on new information.
2. **Replace initial estimates through secondary research.** Often, there is readily accessible academic research or other data and results that can significantly reduce previous uncertainty. This includes public literature as well as data stakeholders have already gathered.

Occasionally, variables remain in the model with the original modellers' estimate, which often cover a wide range. There are three explanations for this: the variable is something that lies in the realm of the modellers' expertise; the variable has little to no information value; or the difficulty in reducing uncertainty exceeds the benefit. The topic of uncertainty reduction will be covered more robustly in the Information Value section that follows.

Table 10.1. General model statistics.

Statistic	Quantity
Total number of uncertain variables	149 variables
Unique variables (excluding time series for rainfall)	100 variables
SME calibrated estimates	53 variables
SME input and secondary research	20 variables
Stochastic variables for rainfall	50 variables
Estimates based on local historical data	2 variables
Secondary research alone	24 variables
Duration (years) modelled on Cash Flow	50 years
Line items (rows) on Cash Flow	191 rows

10.4 Audit procedure

A structured audit procedure was followed. Ideally, the audit is a formality that merely confirms good modelling practices. However, for even simple models an auditor must assume errors are inevitable.The project manager or model creator will either record three known errors before the audit or add three errors. The audit will be evaluated by whether the auditor finds all of the errors. The auditor should have knowledge of the model but should not have been a major contributor to its construction. The individual who creates the model will provide support, help further familiarize the auditor with the model, and be available to answer questions about the model.

The audit procedure consists of eight steps listed below. The audit centres on two of the sheets in the model: the Inputs Sheet and the Cash Flow Sheet.

Inputs Sheet:

1. Confirm that all macros run without error.
2. Run a trial Monte Carlo on the output of interest and Value of Information Calculation and investigate results.
3. Check Inputs page for any variable that does not feed through to the final calculation of NPV or ROI. Note any "orphans" on the Issues sheet even if modeller has noted the orphan in comments.
4. Check comments – are estimations documented with source and date? Note any ranges that are not sourced correctly on the Issues log page.
5. Check all variables that had information value and investigate their pathways to the calculation of NPV.

Cash Flow Sheet:

6. Go to the NPV output on the Cash Flow or Random Cash Flow sheet and work backward through the Cash Flow logic, checking logic for errors.
7. On the Cash Flow Page, check for consistency of formulas on rows.
8. On Random Cash Flow page make line graphs of all the section summary rows to visually check for logical results on many different scenarios.

Once these steps are completed, the project manager or model creator will see if the auditor found all three of the previously known or added errors. If not, the audit process will be repeated. If all errors were found, then the audit procedure is concluded and any discovered errors are fixed.

10.5 Value of Information calculations and measurements

> **What does an information value of zero mean?**
>
> Eliminating information value simply means that no economic justification remains for further reducing uncertainty on a variable and is an expected result in the progression of model development. Information value on a single variable only exists when the existing uncertainty on that variable could tip the balance for the entire investment

10.5.1 Iterative reduction in information values and uncertainty

As mentioned in the detail of the methodology of Applied Information Economics the term "information" is mathematically well defined and has an economic value that can be computed[9]. This calculation, which has been part of decision theory for 70 years, can be used in investment decisions to direct attention and measurement activity to where it will actually reduce uncertainty in the investment.

In this project, the Value of Information (VIA) was calculated over six iterations, which is consistent with the Applied Information Economics process (see steps two through four in Figure 7.2). In the six iterations a total of twelve variables had high information value. These initial information values are large – some in the billions of US dollars. But that is consistent with modelling a major highly uncertain decision of this scale with 50 years of costs and benefits. Again, this was treating the decision as if Elion was yet to make this major decision. This effort was asked to determine whether the investment was a good decision. Still, this same analysis can be a guideline for future possible desert greening efforts where decisions are yet to be made.

Many of these variables appeared repeatedly but this was not always the case. For example, early in the modelling process (Table 2) there were five variables with a significant value of information. Later in the modelling process (Table 3) uncertainty had been reduced sufficiently that three of those five variables no longer had information value – while significant values remained for the other two.

[9] Generally the measurement of value of information is calculated in projects where the investment is yet to be made. In this case, it is a retrospective analysis where the investment has already been made, but the information values function in the same way – they are still relevant for reducing uncertainty on how likely this project has produced (and will produce) a net benefit.

Table 10.2 lists the actions taken to reduce uncertainty between two VIA calculations, and the change in information value seen in Table 10.3 demonstrates the effect this uncertainty reduction had on information value. Remaining information values are less than 5% of what they were in the previous iteration, however this still represents a significant level of uncertainty.

Various methods of reducing uncertainty can be used including variable decomposition, refining estimates with more SME input, secondary research, refining the logic of the model, and making empirical observations. Original empirical research was outside the scope of this review but the other methods all played important roles in reducing uncertainty:

- *Model decomposition* resulted in eliminating information value on two of the high information value variables – "Average profit of crops," and "All water needs of vegetation in the project area." In the early versions of the model, these variables were highly aggregated. Since these aggregated variables had a high information value, they were decomposed – in subsequent models cost, revenue, water uptake, and area of cultivation were given for individual crops.

- *Refining estimates with SME inputs* resulted in eliminating information value on five of the variables: "Per cent chance desert greening has no effect on runoff," "Total

Table 10.2. Information values found in the fourth iteration of analysis

Variable Name	Information Value	Measurement Action Taken
Daily Wage, Kubuqi Project area labourers	$1,681 million	Reduced range based on secondary research.
Percent of *Salix, Caragana, Hedysarum, Haloxylon,* & grasses and shrubs grown for profit	$1,286 million	Reduced range based on workshop with SMEs.
Average Yield, *Haloxylon* (kg/ha)	$497 million	Increased lower bound from secondary research.
Initial Costs of desert restoration	$382 million	Set up decomposition. Decreased upper bound based on new input from SMEs.
Food inflation relative to general cost inflation over 50 years	$368 million	Decreased upper bound from secondary research

Table 10.3. Information values found in the final iteration of analysis.

Variable Name	Remaining Information Value
Daily Wage, Kubuqi Project area labourers	$12.1 million
% of *Salix, Caragana, Hedysarum, Haloxylon* & grasses and shrubs grown for profit	$11.9 million

hectares, all crops," "Hectares of Liquorice", "Current average water table depth," and "Initial costs of desert restoration." For most of these variables, simply asking the right SME resulted in a radical reduction in uncertainty. For the variable "initial costs of desert restoration," we relied on both more SME input and on decomposition to eliminate information value.

- *Model developments, secondary research, and uncertainty reductions in other variables eliminated information value on three variables:* "Annual inputs, not related to direct farming costs," "Average yield of Haloxylon," and "food commodity inflation" all had large information values in one or more of the value of information calculations but ceased to have information value as uncertainty in the model was reduced and the average outcome of the investment became more positive.
- *Refining estimates with SME inputs, and secondary research reduced* but did not eliminate information value on the remaining two variables: "Daily wage for Kubuqi Project area labourers" and "Percent of grasses and shrubs grown for a profit." The second variable includes five of the groups of plants grown in the Kubuqi Project area: *Salix psammophila, Caragana microphylla, Hedysarum scoparium, Haloxylon ammondendron,* and "all air seeded grasses and shrubs."

10.5.2 Additional comments on the VIA process

The following observations are made from the VIA calculations:

1. All the further refinements ended up being within the stated bounds, but narrower. This indicates that the initial calibrated estimates were reasonable. That is, they indicated higher uncertainty but contained subsequently confirmed values.
2. When uncertainty is reduced it can either make the investment more attractive or less attractive depending on how the range changes. For this project, almost all of the uncertainty reductions favoured the investment. The only exception was the percentage of various shrubs that were harvested for forage and sales of herbaceous plants – the upper end of this range was reduced which decreased projected revenue from this source.
3. The value of information was computed from the point of view of the investor making a decision as if this were the beginning of the Kubuqi Desert Greening Project. Over a 50-year period, this turned out to be large investment. This would tend to increase information values relative to the decision of simply making a small expansion to the existing area.

10.5.3 Remaining information value

As noted above, total information value had dropped by 95% by the last time information value calculation was run. Recall that for information value to exist there must be a cost of being wrong and a chance of being wrong. In this case, "wrong" would take the meaning that all of the benefits of the greening project did not outweigh all of the costs of investment and maintenance. While the likelihood of this had dropped to roughly 12.5% (see later) the size of the investment means that significant information value still existed. Only two individual variables remained ("labour costs in Kubuqi Project area" and "percent of grasses and shrubs used for harvest") with high information values:

1. The harvest percentage of various shrubs and grasses was one of the two variables remaining with high information value. As long as more than 9% of these plant species were harvested for forage or sale, the investment as a whole is positive. It is very likely that tracking individual species and making empirical measurements would remove much of the remaining uncertainty and information value in the model.
2. The cost of labour in the Kubuqi Project area continued to have a high information value. It is likely even easier to reduce uncertainty on

this variable with empirical measurements, or just by finding a resource with more familiarity with labour levels in this region. There is also a notable caveat – the information value on the cost of labour only applies when looking at the labour as a cost only. If the objectives include the benefit of local incomes from Kubuqi Project work, this would wipe out the information value – because in that case it would be both a cost and a benefit.

Also of note, while no single variable in plant species or water budget had a positive information value in the final calculation, the combined group has an information value of about $2,550,000. Again, these values were from the point of view of making an investment now in the long term for these benefits, not the information value for the Kubuqi Project (which is already done). So a resulting recommendation is that if someone were to replicate a project of similar scale elsewhere, a more detailed hydrology and plant uptake model would be justified.

The information values related to water increase significantly depending on the financial discount rate. Elion, like many corporations, may apply a discount rate to future benefits. In this model a wide range of discount rates were allowed (anywhere from 2.5% to 20%). This means that in Net Present Value terms a benefit in 50 years could have less than 1/100th or even 1/1000th of the value of the same benefit this year. With a constant discount rate above a few per cent, a major cost to the environment in the distant future (such as depletion of the water table) has a significantly reduced impact. But environmental decisions tend to put higher values on costs and benefits in the distant future. In these cases, we resort to an "environmental discount rate" of less than 2%. At a discount rate of 1% the value of a benefit (or cost) in 50 years is about 60% of what it would be if experienced this year. In this case, the impacts of potentially negative outcomes decades from now are much more prominent in the model. This indicates that, even for this project, which was decided upon 30 years ago, the monitoring of the water table and even further modelling of complex hydrology has a high value.

10.6 Modelling results

The final model was used to simulate 10,000 potential outcomes for four questions:

1. Was the Kubuqi Desert Green Economy Project an investment with a positive return for Elion?
2. What is the risk of future declines in the water table?
3. What is the risk of declines in local income due to overuse of the water table?
4. Should the project be expanded further?

Finally, we will review some issues that are not explicitly addressed in the model and the recommendations implied by these results.

10.6.1 Investment results

The average net present value (NPV) of the investment was a benefit of $1.84 billion. This means that for over 10,000 scenarios (incorporating all the uncertainty of both costs and benefits) the average outcome was a benefit of $1.84 billion. The distribution of the possible NPV is given in Figure 10.2 and the other basic metrics of the most recent Monte Carlo simulation are found inTable 10.4.

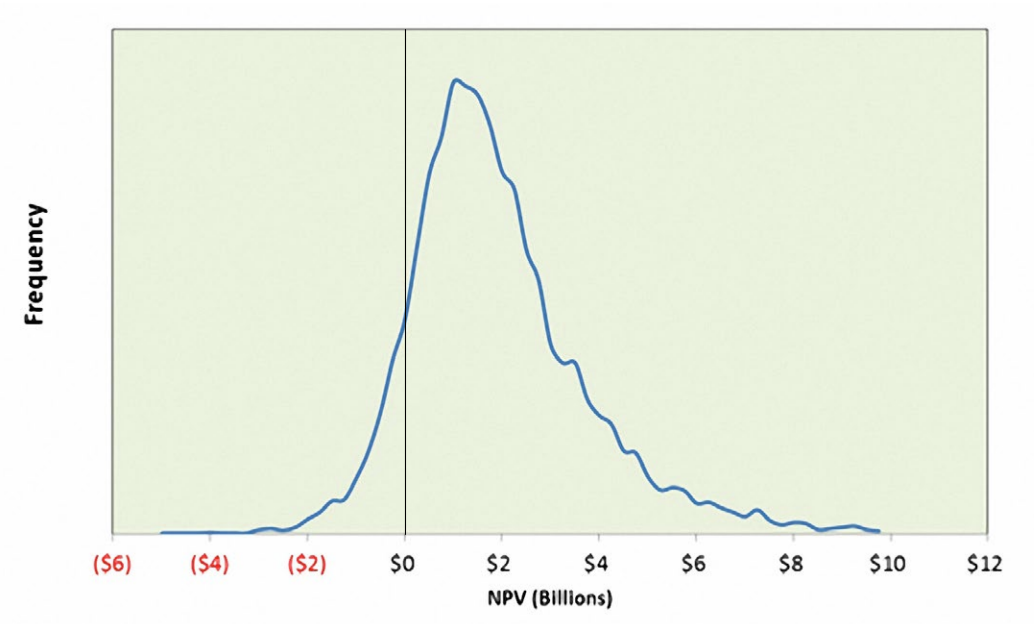


Figure 10.2. Distribution of results for the net present value of the Kubuqi Green Economy Project.

Table 10.4. Metrics for the Kubuqi Project Monte Carlo simulation.

Metric	Value
Trial Count	10,000
Chance of negative return	12.1%
Expected Opportunity Loss	$84 million
Average outcome	$1.84 billion benefit
Median outcome	$1.51 billion benefit
Mode outcome	$1.01 billion benefit
5^{th} Percentile outcome	-$640 million (loss)
95^{th} Percentile outcome	$5.50 billion benefit

These results indicate that if the Kubuqi Desert Greening were a decision to be made now instead of 30 years ago, it most probably would be a positive return. However, there is still a 12% chance of a negative NPV for this investment over a 50-year period looking strictly from the point of view of the investor seeking a return on investment. For such a large investment this risk might not be acceptable for many of the largest corporations in the world.

However, from the point of view of the general community the return is higher, primarily because of the beneficial aspect to local incomes.These are partially captured in the following sections.

The breakdown of major costs and benefits is shown in Table 10.5. The largest cost is the initial cost of restoration and the irrigation costs are small by comparison. Agricultural revenues dominate the benefits.

Table 10.5. Best estimate and range for the cost and benefits of major model components.

Component	Lower Bound	Best Estimate	Upper Bound
Costs			
Costs of irrigation	$0.044 million/year	$3.52 million/year	$12.2 million/year
Other agricultural costs	$19.2 million/year	$75.8 million/year	$190 million/year
Initial costs of restoration	$60 million (one time)	$271 million (one time)	$3.4 billion (one time)
Ongoing costs (non-ag)	$0.51 million/year	$1.30 million/year	$6.03 million/year
Benefits			
Agricultural Revenues	$26 million/year	$105 million/year	$305 million/year
Non-agricultural benefits	$4.2 million/year	$17 million/year	$44 million/year

Note: There is a ninety percent chance that the actual values are between the upper and lower bounds. The ranges given may be considered wide but represent the calibrated levels of uncertainty for each variable.

10.6.2 Risk of future decline in the water table

One of the primary objectives of this analysis was to assess sustainability of the project, and a large part of the sustainability issue depends on the possible changes in the water table. The model incorporates total plant needs, estimates evaporation and runoff, area of the water table relative to the project area and many other relevant variables. These variables are used to produce a dynamic water table – each year the level of the water table can move up or down or stay constant depending on all of these factors (Figure 10.3, Figure 10.4). There is both a maximum depth of the water table (where the water column hits bedrock) and a minimum depth (where springs and other features would provide an outlet for water to overflow).

In a slight majority of scenarios (55%), the water table is stable – that is, water inflows to the water table equal or exceed outflows. In 70% of scenarios, the water table would decline less than one meter over fifty years. In only 2% of cases was the water table exhausted over a 50-year period. It is important to note that even though this is a relatively low probability, it has important implications for policy and planning future projects or expansions. Although the information value from this possibility is low[10], there are some caveats to this. First, as noted in the VIA section, even though no single water

[10] Even in the rare cases when the water table dries up, it is late in the 50-year analysis and rarely has a significant effect on NPV. Why might the information value be low? Consider that if the water table dried up in Year 50 a Net Present Value of the first 50 years of the project investment would not reflect the negative implications of this.

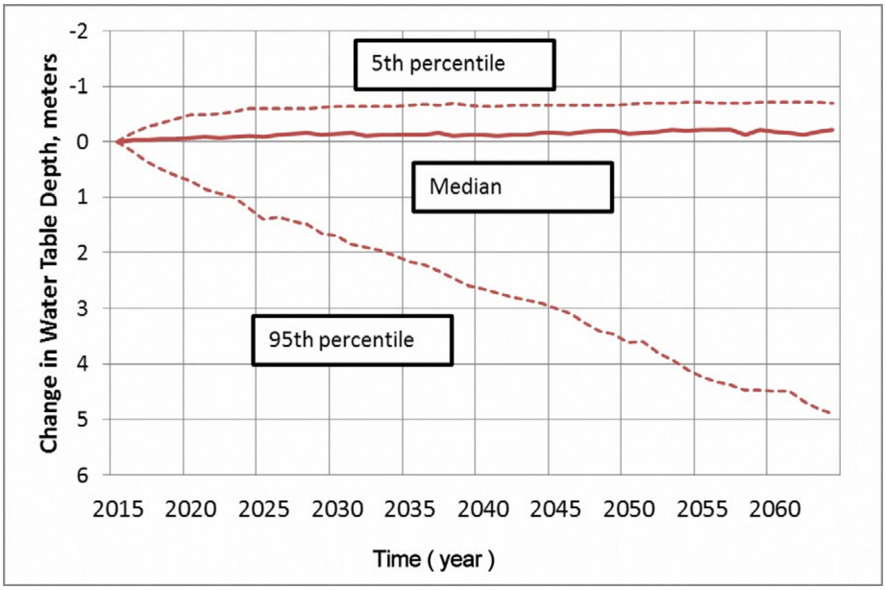


Figure 10.3. Potential changes in water table depth over 50 years.

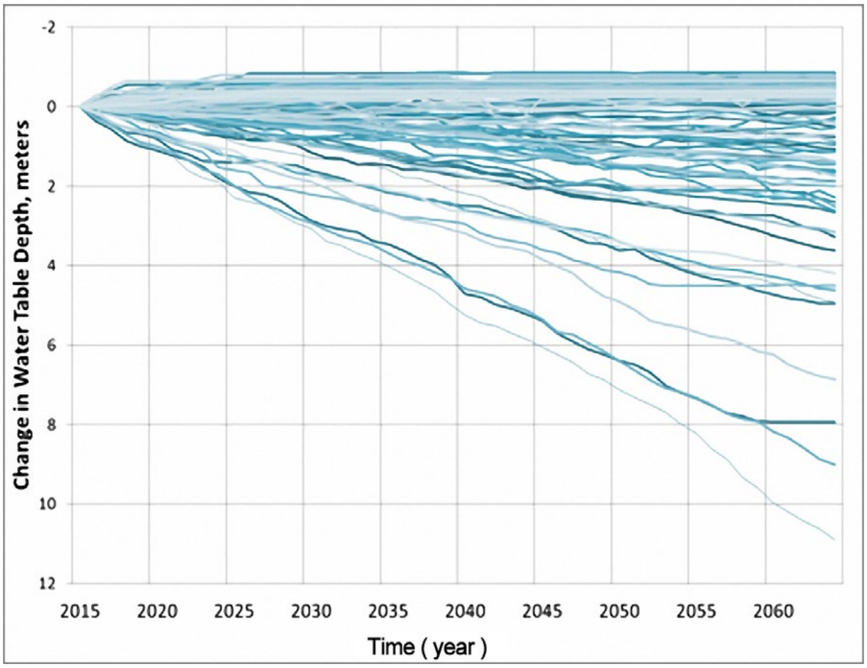


Figure 10.4. Examples of some individual simulations of changes in water table depth.

table variable has information value the group has a significant information value, and the cost of tracking water use and water table depth on an annual basis is low. Second, if an expansion of the current project area is being considered, the likelihood of drying up the water column increases, as does the information value. Third, there are potentially negative effects not being considered – there could be downstream costs even if the water table is constant, simply because the irrigation water would otherwise overflow out of the water table into local streams and rivers, with potential impacts on downstream populations and their livelihoods.

10.6.3 Risk of declines in future incomes

Future incomes depend on the sustainability of the greening given the resource constraints of the water table. If the water table becomes exhausted, it would have dramatic impacts on yields and therefore on incomes. Even before the water table would be exhausted there would be an increase in irrigation costs for pumping energy and drilling. This risk of an income decrease can be expressed as a type of "Loss Exceedance Curve" (LEC). This is a method of communicating risks common to the insurance and financial industries. The LEC shows the chance that a given or greater loss would be experienced. In this case, we can show the chance of a decrease in income of a given amount or worse over a 50-year period.

Figure 10.5 below shows the results of this simulation on the chance of various levels of a decrease in income. The simulation shows that incomes stay the same or increase 92.5% of the time. Consequently, this chart shows that the simulation from the model generated some drop in income in 7.5% of scenarios from the time period between 2015 and 2065. It also shows that a 25% drop in real incomes over that same period happens in about 2% of scenarios. This risk of a decline in income is due mostly to a risk of overuse of the water table in agricultural incomes. A hypothetical, unofficial "risk tolerance" curve was gathered from Elion management in one of the workshops. This risk tolerance curve is not an official position of Elion. It merely reflects preferences for risk among some in Elion management. The chart shows that the simulated risk of income decrease is somewhat higher than the preferred risk tolerance for the managers who participated.

Ideally, tools like this would be used to gather stated risk tolerance from representatives of the local population. Some degree of risk is virtually unavoidable but a quantitatively unambiguous LEC can communicate what risk would be acceptable. When any part of the simulated risk is above the risk tolerance, then some risk mitigation strategies should be employed to reduce the risk until it meets the stated risk tolerance at every point.

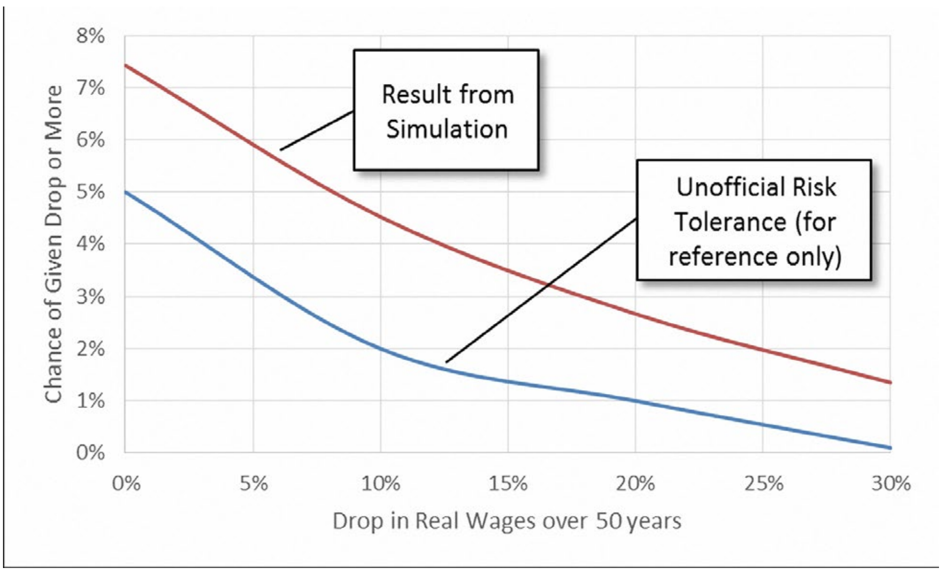


Figure 10.5. Simulated loss exceedance curve for income decrease versus unofficial risk tolerance.

10.6.4 Further expansion of the Kubuqi Project

Overall, the risk and return of further greening will be at least as good as the risk and return of the greening effort so far. Since certain infrastructural investments have already been made, further expansion is done with the same benefits but with lower initial investment costs.

When the Kubuqi Project first started, initial investments would have been in the range of \$350 to \$600 per hectare (including soil fixing, seedling bases, etc.). Further expansion is expected to cost 20% to 80% less on average. So from a risk/return point of view, each additional hectare of land converted from desert to green is at least a near term benefit with relatively little risk of being a poor investment. Especially from the point of view of the local population, additional greening is desired in the short term.

The primary risk is the risk of long-term over-exploitation of the water table as the project area expands. While there is currently some risk of overuse of the water table, that is mitigated in part by the fact that the developed project area is probably a fraction of the area of the entire water table. It is also mitigated by the fact that high water use species, such as non-native vegetables and trees, are only a portion of the developed area, the remainder being mostly plants native to desert areas. If the project area expands, and especially if the area dedicated to higher water use plants expands, then the risk of water table depletion grows.

10.6.5 What the model doesn't address

Even though the model has over 100 individual variables, some simplifications had to be made. It has already been pointed out that, as an abstraction, this model or any other will have to leave out some detail. The complexities of hydrology, plant physiology, weather, and local economics were simply implied by the use of wide ranges for estimates of the variables the model did contain.

Also, while the model attempts to estimate both agricultural and some non-agricultural incomes, it does not attempt to measure the improvement of overall quality of life to the local rural population beyond the effect of fewer sand storms on reducing health costs. The analysts involved in this assessment have applied these methods to problems related to environmental policy and health and safety and these effects could be quantified given a larger effort.

The benefits to the population were due to a combination of inputs besides the greening of the desert itself. There was also a long-term commitment of the investor, Elion, to reinvest profits to the benefit of the local population. Schools, infrastructure, new higher paying jobs, and more were all developed as a result of this commitment by Elion. It was not the objective of this effort to assess the impact of both the greening project and the continued social investments of Elion, which were significant.

10.6.6 Implications for other desert greening projects

One advantage of keeping the model at a relatively high-level without too much detail specific to this area is that it may help it be more applicable to other potential sites. The results can be seen as more fundamental to desert greening in general. A few points should be made about how to extrapolate these findings to other projects:

1. The Kubuqi Desert is not as dry as some desert locations in the world. A desert is generally defined as an area with less than 500 mm of rainfall per year but many deserts have rainfalls of well below 200 mm per year. Kubuqi has an average rainfall of 280 mm per year. On the other hand, Kubuqi is a temperate desert with cold winters, and hydrological conditions in hot deserts may be less favourable for sustaining plant growth. The proximity of the project to the Yellow River is also a factor to be considered, together with the fact that river flows are derived from snow melt in the Tibetan

Plateau.

2. The Kubuqi Desert Project manages water consumption in part by using a large proportion of species native to the desert and then only developing a portion of the total area. The long-term drain on the water table will be driven primarily by non-native trees and vegetables. As long as the proportion of these plants is small compared to the total area of the water table, other projects could be sustainable.
3. The Kubuqi Desert Project could make straightforward empirical measurements of water table levels and irrigation water usage to reduce uncertainty. To reduce uncertainty on the hydrological aspects of a greening project in the future would almost certainly benefit from more complex modelling of hydrology and plant physiology.
4. A long-term commitment is necessary. Whatever the source of funding, the wait time for significant benefits will be in the order of decades. Incremental development where some areas can be economically self-sustaining earlier will support continued development.
5. Public subsidies may be justified. The benefits of greening a desert go well beyond the financial benefits to a corporate investor. Reductions in sandstorms, increased tourism, and overall improvements in quality of life are benefits not solely realized by the investor.

10.7 Recommendations from the modelling

In summary, the following are the key recommendations one could make based on these results:

1. **Consider greening for similar deserts.** Projects like this may be justified in other parts of the world in areas similar to the Kubuqi Desert (temperate deserts where rainfall is over 200 mm/year) with accessible ground water. Also, similarly moderate temperatures and humidity make evaporation less of an issue here than it would in drier deserts. Areas that have suffered recent desertification would be ideal candidates.
2. **Develop a more comprehensive model of the interactions of hydrology and plant physiology.** Ideally, future desert greening decisions would utilize more detailed yield curves showing yields as a function of water usage, water uptake models, and hydrological interactions among various areas of the water table, rivers, and bodies of surface water. Even for currently greened areas – such as Kubuqi – a somewhat more elaborate water model would inform decisions about future expansion and other management decisions.
3. **Monitor the water table level and irrigation usage on an annual basis.** Track on a year-to-year basis and see what is happening to the water table in several points across the project area. The cost of such tracking is low and would have direct consequences for management decisions – such as whether to decrease the more water intensive plants on the project area or conversely to expand the project area.
4. **Further expansion decisions should be taken only if better water table tracking and a more detailed model support it.** There is a risk of long-term overuse of the water table. A key factor keeping the depletion of the water table low at this point is the limited area of the development compared to the larger area of the entire water table. If the area requiring irrigation grows significantly, or the area grown under trees and crops with large water requirements increases, these risk overuse of the water table in the long term. If better tracking were in place and if the data from that tracking were feeding a somewhat more detailed model, expansion could occur while managing the risk of overexploitation.

11 Conclusions and recommendations

11.1 Green economy model

Green economy is designed to promote economic progress with positive social outcomes in a way that does not push our ecological footprint beyond planetary boundaries. A green economy is resource efficient, socially inclusive, and seeks to ensure environmental security by maintaining resilient ecosystems. Growth in income and employment should be driven by public and private investments that at the same time reduce environmental risks, enhance energy and resource efficiency, and conserve biodiversity and ecosystem services (UNEP 2011b).

How well does the Kubuqi Project measure up to these criteria? The Elion conceptual model of green sustainable development is expressed by two cycles: a social cycle of desertification prevention control, industrial development, livelihood improvement, ethnic harmony, and harmony between nature and people; and an economic cycle of desertification prevention and control, eco-restoration, land reclamation, and industrial development.

During the past 26 years, Elion has built five roads across the Kubuqi Desert, combined with a power, water, and telecommunications network. A key to the success of these investments has been their protection from wind blown sand by an innovative 242 km long “green ecological barrier”. In addition the surrounding desert shifting sands have been stabilized through afforestation of over 5,000 km^2.

These green engineering developments have benefited government, enterprises, farmers and pastoralists. A pharmaceutical industry has been built up around the harvesting of desert plants and a building materials industry based on sand raw materials, supplemented with investments in renewable energy. An eco-tourism industry has been established based on the increase in biodiversity as well as interest in the green economy model itself. Profits from these enterprises have been channelled back into expansion and further innovations in desert restoration and social infrastructure such as improved housing and schools. The developments have created new markets and employment opportunities and improved living standards of farmers and pastoralists. For example the annual net income of farmers and herdsman has risen from RMB 2,000 in the year 2,000 to more than RMB 30,000 in 2012, lifting many out of poverty. Environmental quality, especially as a result of reduced frequency of dust storms and reduced sandification has also markedly improved. Soil health, especially organic matter content, in planted areas has improved.

The average net present value (NPV) of the overall desert green economy investment is a benefit of $1.8 billion. The probability distribution of the net benefits is quite broad and there is a 12% chance of a negative NPV for this investment over a 50-year period. However this analysis does not include the off-site social benefits of the project, which are substantial, nor does it include the off-site costs of over-use of groundwater.

The largest uncertainty with respect to sustainability of the Kubuqi Desert green economy model is the impact of irrigation and water use by trees on water table depths. To date, the impacts have been relatively minor, with local opinion suggesting less than 10 cm per year, and a lowering of not more than 1 to 3 m since the start of the project. Simulations suggest a chance of only 2% of water table depletion over the next 50 years, but a 45% chance of some further draw down. Planting of trees, especially at high densities, as distinct to adapted shrubs and grasses, should be restricted to shelterbelts and limited in area to reduce the risk of using up fossil water in the subsoil and causing water table drawn down, which would also result in tree mortality, especially when trees become large, for example 20-30 years after planting. Monitoring of water table depths and more comprehensive modelling of the hydrology of the area are recommended as high priority. Continued investments in water saving technology and utilization of plant species that have low water use are also recommended to reduce hydrological risks.

Expansion of the desert greening to adjacent areas is likely to provide a similar return and risk as past investments. Since certain infrastructural investments have already been made, further expansion is done with the same benefits but with lower initial investment costs, although this could be partially offset by increased irrigation costs as planting moves into area with less favourable hydrology. When the Kubuqi Project first started, initial investments would have been in the range of $350 to $600 per hectare (including soil fixing, seedling bases, etc.). Further expansion is expected to cost 20% to 80% less on average. So from a risk/return point of view, each additional hectare of land converted from desert to green is at least a near term benefit with relatively little risk of being a poor investment. Especially from the point of view of the local population, additional greening is desired in the short term.

The primary risk is the risk of long-term over-exploitation of the water table as the project area expands. While there is currently some risk of overuse of the water table, that is mitigated in part by the fact that the developed project area is probably a fraction of the area of the entire water table. It is also mitigated by the fact that high water use species, such as non-native vegetables and trees, are only a portion of the developed area, the remainder being mostly plants native to desert areas. If the project area expands, and especially if the area dedicated to higher water use plants expands, then the risk of water table depletion grows. Therefore we would recommend a thorough assessment of water resources before extending to new areas so that the risk of water table depletion can be managed in terms of planting the appropriate species at suitable densities for the local hydrological conditions.

11.2 Success factors

A number of geographical, political and social factors have combined to create the successful Kubuqi Desert green economy model. The favourable groundwater conditions in the project area, with groundwater within several metres of the land surface in preferentially planted areas, have created a favourable environment for tree establishment and growth. These conditions have arisen because of the proximity to the Yellow River and the geology of the area. Availability of a source of irrigation water from confined adjacent aquifers has also helped.

The high degree of scientific and technical innovation in tree selection/ breeding, establishment, irrigation, and management has been critical to success. In particular the water jetting technique for tree establishment was a major breakthrough, increasing tree survival rates from 20% to over 85%, speeding up planting and reducing costs. The sand barrier technology was critical for protecting the investment in infrastructure. Drawing on indigenous knowledge and tree germplasm resources has also been instrumental in selection of adapted species that are drought and salt tolerant and with low water requirement and at the same time yielding useful products. The high level of scientific and technical innovation extended to the pharmaceutical and sand industry and allowed productive use of desert resources (plants and sand).

Early investments in infrastructure were a driving force for desert greening, first creating a need for protection against sandification, and then creating market opportunities and encouraging investments in desert industry. This in turn stimulated investments in social infrastructure such as improved housing, services and schools.

State policy on land ownership and natural resources management not only provided an enabling policy environment but also acted as a major driving force for desertification control efforts. Revision of policies on land ownership during the decentralization phase and clarification of ownership of land, use right of land and household responsibility created incentives for investment in tree planting. The series of natural resource management policies and laws enacted from 1978 to 2000 and several major desertification control campaigns after 2000 all provided momentum for greening efforts.

Strong public-private-public partnerships were perhaps the most important ingredient for success. Government enabling policies facilitated private and community involvement and strong partnerships. Elion in particular played a major role in balancing ecological improvement and business operation as well as infrastructural co-investments. Long-term vision and thinking have been critical, especially given the long time frames (20 to 30 years) required for realisation of benefits from tree planting interventions. Elion also formed key partnerships with scientific and technical institutes, which in turn contributed to technological innovation. The government and Elion mobilized local communities behind the greening efforts through enabling laws, policies and incentives, mentioned above, as well as creation of employment and market opportunities, and development of business organizations and community institutions.

A key feature of the public-private-community partnership has been an adaptive learning process.The achievement of desertification control in Kubuqi Desert and its link with an enterprise like Elion was not derived from a complete plan or knowing everything before taking any actions. Audacity, innovation building on local knowledge, and adjustment of plans based on accumulated experience and knowledge have all been key contributions to the evolution of desert green economy.

The leadership of the executive body of Elion Resources Group constituted a major driving force behind the desert greening initiative. Re-investment of profits from Elion’s enterprises into both business and social development in the region has reinforced local community commitment to the project. Fostering partnership with the government at an early stage in the project both helped the project and helped shape government policy.

11.3 Considerations for scaling out desert green economy

The previous section pointed to key elements that might be considered in scaling out the Kubuqi Desert green economy model to other desert or dryland areas. These may be distilled further into a set of principles for sustainable desert green economy projects:

1. Make productive use of indigenous germplasm and related knowledge, combined with technological innovation.
2. Ensure access to a sustainable water resource for supplementary irrigation and use efficient irrigation technologies.
3. Develop industry around the utilization of tree and desert plant products.
4. Manage the project to minimize and carefully manage the area under fast-growing trees and exotic and high values crops that have large water demands, to reduce water consumption, and maximize the area under indigenous vegetation with low water demand.
5. Introduce government policies that (i) provide secure tenure of land, trees and tree products, (ii) provide incentives for tree planting and long-term management, (iii) encourage and stimulate public-private-community partnerships in development of desert green economy enterprises (this includes early investments in infrastructure to encourage investment in remote areas and market access), and (iv) facilitate government investment or public payment for ecological services that might be brought to the public beyond local investors, and (v) encourage private sectors to invest in ecological public welfare.
6. Develop a vision and plan for long-term investments combined with an adaptive management and learning approach. In particular, encourage visionary leaders in local communities, local governments and the private sector to promote long-term investments in desert green economy.
7. Encourage long-term thinking by investors. The waiting time for significant benefits will be in the order of decades. Practice incremental development where some areas can be economically self-sustaining earlier to support continued development.
8. Encourage re-investment of a significant portion of the profits back into to the desert enterprise and associated social infrastructural developments (e.g. improved housing, schools and services).
9. Consider public subsidies as the benefits of desert greening go well beyond the financial benefits to a corporate investor. Reductions in sandstorms, increased tourism, and overall improvements in quality of life are benefits not solely realized by the investor.
10. An Applied Information Economics analysis of future green economy investments would help to improve plans and pinpoint areas where further information and monitoring would have high information value for improving green economy investment decisions.

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