Transformational restoration: a case study from Denmark

Palle Madsen, Jens-Peter Barnekow Lillesø and Lars Graudal, Forest & Landscape, Dept. of Geosciences and Natural Resources Management (IGN), University of Copenhagen. pam@ign.ku.dk

Overview table

Denmark	
Objectives	The restoration of the severely degraded lands was – some of it heathlands – was initiated increase production of wood for a society short in almost all natural resources following several hundred years of unsustainable forest and land management by overharvesting and –grazing. Only about 2-4 % forest was left. Much later in the 1980's other the range of restoration objectives increased considerably to include e.g. biodiversity, recreation, ground water protection, hunting and other aspects. Even a temporal objective of reducing the surplus production of farm products was on the agenda in the 1980's
Duration	More than 200 years
Target area to be restored	Latest target (intention) involves doubling the forest area to around 800.000 ha based on the 1989-level considered to be around 400.000 ha within a "forest tree generation" (80-100 years)
Stakeholders and organisation	Private landowners (large and small), state forest service, municipalities, foundations, water companies – shifting impact over time
Funding	Initially, predominantly private investors (large and small) and government. In modern time more driven by government and EU-subsidies, that varies from year to year on private land as well as government budget for public afforestation

Abstract

Forest restoration in Denmark stretches over a 200 year history or more. FLR according to modern definitions has not been on the agenda throughout all of that period – and it's still not a well-known concept among Danish stakeholders even today in spite its elements are implemented to some degree in practice. But there are lessons to be learnt about important technical and societal elements and appropriate time scales of the process to consider which are relevant for today's global FLR efforts.

Afforestation was initially the prime activity within the Danish forest restoration efforts, and it still is important and ongoing. One important take-home message is that the plantations planted with non-native species on the severely degraded heathlands after several decades started offering site conditions that allow the establishment of a wide range of species including the native broadleaves.

As such this restoration trajectory covers a period of decades or more than a century. This is illustrated by the fact that the initial efforts to establish native species on the degraded heathlands was tested and found impossible. Even if the full package of FLR had been on the agenda those days it would have been impossible to install both for biophysical and economic reasons. However, plantations of non-natives have as such – over time – paved the road for a more comprehensive FLR approach. Besides, the non-native species today contribute to the adaptation capacity of the European forests that compared to other continents are poor in tree species diversity due to the multiple Pleistocene ice-ages.

These plantations were initially planted with a very narrow focus on producing wood. This focus in restoration and forestry has shifted up through particularly the 1980's towards more attention on the re-introduction of ecosystem integrity and multiple functions and a wide range of ecosystem services. The forest restoration approach of today is as such including more and more of the FLR elements. Forest productivity and capacity of storing carbon is climbing the agenda due to needs for mitigation measures. Projections for the future forest contribution to mitigation of the CO_2 emissions indicate that total carbon storage and fossil fuel displacement potentially may increase from less than 5 mio tons of CO_2 year^{-1} to 10-13 mio t year^{-1} by 2100.

Initially, there was no national target identified but the forest land area increased from 100,000 ha around 1800 and reached app. 400.000 ha by 1989. The government launched in 1989 an intended further doubling of the forest area within the next "tree-generation" – i.e. 100 years to reach app. 800.000 ha or more by 2090. The annual expansion of the forest area today corresponds to 65 percent of the area needed to fulfill the governmental goals; and only 36 percent of the new forest areas are protected against future clearing. Most of the forest land expansion is not a result of a comprehensive afforestation effort that typically would include protection against future clearance.

Multiple landowners, both large and small private landowners, foundations and public landowners have been and still are involved in both afforestation and forest restoration at forest land. A variety of funding and willingness to invest among the landowners themselves have occurred through time.

1. Background

200 years of restoring a severely degraded landscape

The forest restoration history of Denmark is rather long and includes several forest generations over the past 200 years. This historical case is today relevant since it offers insight in a FLR-process that stretches over what can be considered equivalent to two-four forest tree generations (depending on tree species) in planted forest management. As such it demonstrates the potentials of what a forest landscape restoration (FLR) process may lead to viewed in a proper time scale for forest and forest landscape management. The Danish case shows a great variety in outcomes from plantation of non-native conifers to native species forests – very often involving pure single species stands or forest as well as mixed species stands including both native and non-native species (Madsen et al., 2005).

The people who invested in the restoration process from the beginning started their activities in severely degraded landscapes, and it seems very likely that today's forests given the species they include and their performance in growth and vigour, far exceed the expectations of these founders. Some of the open habitats of the formerly degraded landscapes have even been restored to expand or recreate some of the open habitat types of the historic and cultural landscapes although they represent the past degraded conditions. In spite they were degraded they offered habitats for numerous species that had adapted to this man-made and degraded landscape. Restoring forests into closed canopy and high-productive forests changed the habitats and put species adapted open habitats under pressure. This is by some stakeholders seen as an undesired development. For example, only remnants of the formerly extensive heathlands are now to be found, whereas it was a dominating component in the historic and degraded landscape until 150 years ago (Figure 1). The shrinkage of these habitat types have led to loss of habitat and a threatened status for species that were adapted to and perhaps even had developed large populations in these mostly cleared and man-made landscapes of the past (Figure 2; Johannsen et al., 2014).

Figure 1. The Danish heathland dominating particularly the western part of the country until 150 years ago (Painted by F. Vermeren in 1855).

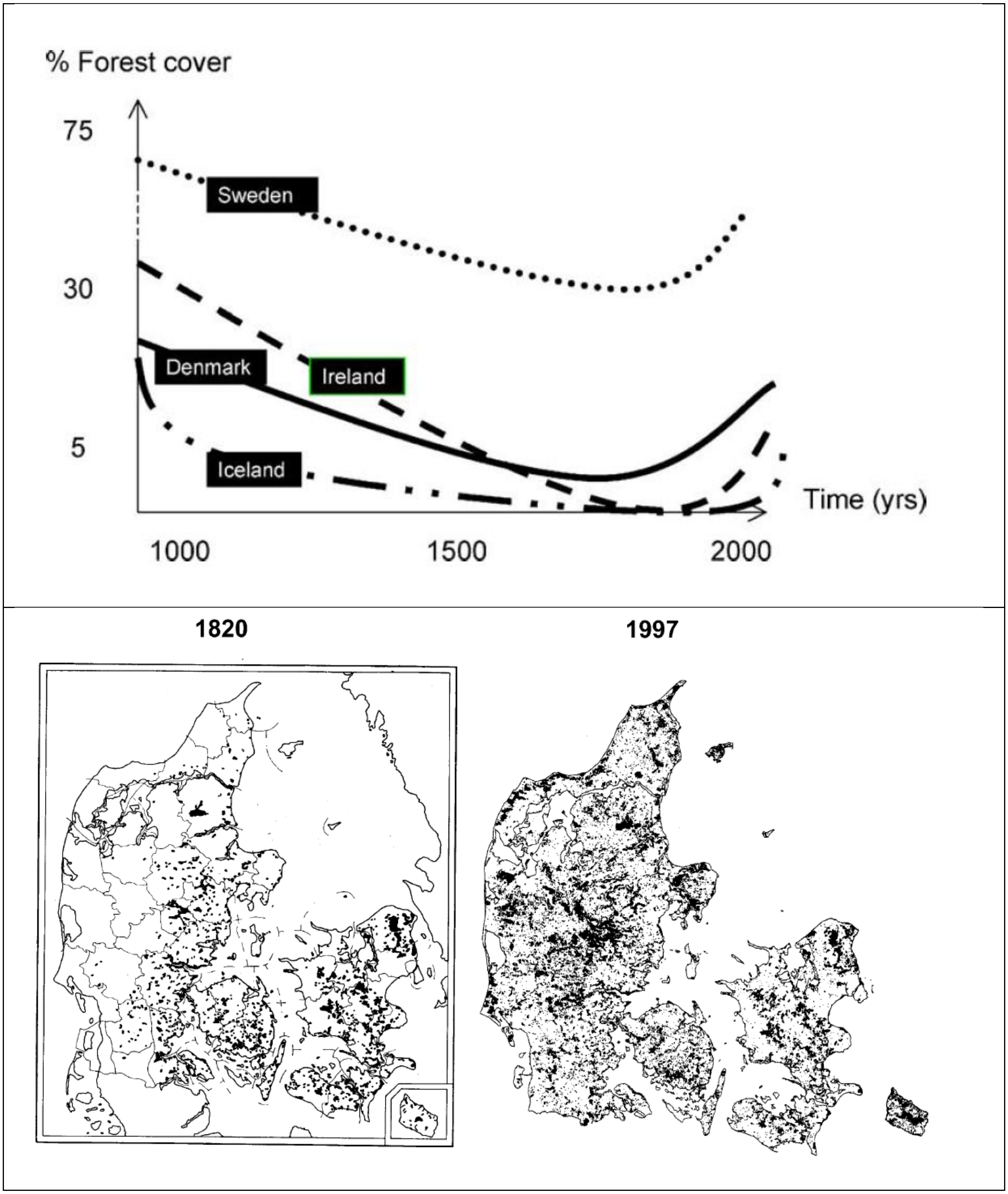

Figure 2. Above: Estimated forest trajectories since 1000 AD in four NW European countries Below: Danish forest cover in 1820 and 1997. Both illustrations are from Bradshaw (2004).

Lessons from historic cases to inform today's FLR

This Danish case is still interesting and relevant as a source of inspiration for present restoration processes. It shows how important it is to adopt both a proper and a realistic level of expectations. For example, it highlights how slow the process may be in the early phases when conditions for establishment of trees may still be harsh and difficult in the degraded landscape - as well as fuelling optimism on the long term expectations and ultimate gains.

Similar FLR-processes took place in other parts of north-western European lowland like the former heathland tracts of northern Germany (Bradshaw, 2004; Mather et al., 1998). However, since Denmark is all lowland (highest elevation 170 m above sea level) the restoration efforts became particularly important for the development of Danish forestry and silvicultural practices since there were no mountainous regions where natural forests were protected against clearance and changes in land use by difficult access and sparsely developed road systems as in most other countries that do have mountainous regions. Therefore, rather, little natural forest survived and definitely no virgin forest (Johannsen et al., 2013).

2. Objectives

What fostered the beginning of a successful movement?

Over a 200-year period, the objectives for forest restoration in Denmark evolved starting with reclamation of severely degraded land to become productive and supply society and the markets with wood, to a broader perspective on restoring forest functionality and supporting society with a wide range of goods and services (Figure 3).

Figure 3. A range of today's most common forest management objectives – profitable wood production, biodiversity, recreation and hunting (Photos by Ole Karger and Palle Madsen).

By 1800 there was only around four percent forest cover left (approximately 100,000 hectares). Degradation peaked around the end of the 18th century when the 1805 legislation was adopted after accelerated forest clearance and decades of failed reforms (Mather et al., 1998).

It is important to understand that forestry and afforestation practises and approaches were rooted in the almost completely cleared and degraded lowland landscapes that came out of many centuries of forest clearing and unsustainable agricultural land-use including overgrazing and fire. Therefore, the initial steps of the restoration process were reclamation and revegetation (Stanturf et al., 2014a and b), where both severe abiotic and biotic constraints had to be overcome for a successful outcome.

For the people and professionals involved, it turned into a mission or a struggle with patriotic dimensions inspired and led by "great men" (Mather et al. 1998). They seemed to inspire the combat of shortages of basic needs and developed professional pride and perfectionism in utilizing the land to gain maximum output of high quality wood products and avoid waste. A similar professional spirit was implemented in farming – probably striving for even higher levels of production and perfectionism than in forestry.

Non-native species paved the road for native species

Danish forest restoration practises are still today characterized by an extensive use of non-native species. The most common approach to restoration has been the functional approach (Stanturf et al., 2014a) under an umbrella of afforestation. Due to the severe growing conditions the afforestation approach could be classified as reclamation, firstly by introducing tolerant non-native species (revegetation and replacement) and later following the new opportunities created by the restored forest conditions, reconstruction and rehabilitation of forests richer in native species. As such more "natural" forest ecosystems gradually became more and more prevalent. From the beginning and up to the 1970s and 1980s, the process was primarily driven by clear objectives of restoring forest productivity to support society with wood products which were considered highly valuable and profitable to produce.

Figure 4. Remnants of the first generation mountain pine nurse crop still exist on the very poor dune areas along the west coast of Jutland (left). To the right is a mixture of Norway spruce and Douglas fir, which is 2nd or 3rd generation at this site - both species are non-native. Such forest regenerates naturally within a range of continuous cover silvicultural systems because mature Douglas fir provides the wind stability needed. Potentially, the re-introduction of native late successional broadleaves by planting or direct seeding is also supported by such non-native forests (Photos by Palle Madsen).

The introduction of non-native species – particularly conifer species – was needed both because the native broadleaves could not establish on the degraded heathlands (Madsen, 2005) and because society and people were in great need of the wood resources for construction and energy. Additionally, overgrazing and fire often destroyed the heather to an extent that the sandy soil was exposed to the wind and could start forming dunes that eventually could threaten houses and villages by covering them. Particularly, on sandy soils those heathlands may be viewed as an endpoint of man-made land degradation under temperate conditions. They were characterized by not only total lack of forest microclimate but also by very acidic soil types (podzols) and as such the conditions for restoring forests were extremely poor. Needless to say that all seed sources had disappeared centuries ago – and relying on natural regeneration or succession was not an option.

The most active restoration professionals introduced and tested a large number of non-native tree species to identify which were sufficiently tolerant and productive under the harsh conditions to secure the process of re-vegetation and reclamation. Except for Scots pine (*Pinus sylvestris*), all productive conifer species – including Norway spruce (*Picea abies*) - are non-native. They still occupy a significant - but decreasing – proportion of the Danish forest area. By 1990 this was estimated to two thirds of the forest area, whereas by the 2013 National Forest Inventory (NFI) it was down to 47 percent of the Danish forest area (Johannsen et al., 2014).

Non-native and native species mixtures in all silvicultural systems

Forestry in Denmark has widely adopted non-native species and replaced coppice and coppice with standards forest systems with high forest systems – and among these, the uniform clear-cutting system (plantation forestry) was the initially the primary system. Further, and particularly on the better sites of Eastern Denmark with higher proportions of native broadleaved forests, other systems were considered and implementation was tested. In beech dominated forests uniform shelterwood systems were implemented (Hahn et al., 2005).

There were also movements surrounding uneven-aged and continuous cover forestry particularly inspired by the central European “Dauerwald” movement in the 1920s and 30s, which was characterized by single tree or group selection. Today, this movement has to a large degree developed into the approach of nature-based or close-to-nature forestry, which has been implemented mainly on public forest land but also partly in privately owned forests (Larsen and Nielsen, 2007).

In contrast with the initial “Dauerwald”-inspired movement and its focus on selections systems, practitioners who now seek to develop and implement close-to-nature forestry primarily focus on the continuous cover aspects and pay less attention to actively implement uneven-aged structures. Such structures have the reputation to depend on intensive management, which usually is not possible due to low profitability. Instead, the main priority is ensuring continuous cover to maintain sheltered forest climatic conditions and avoid clear cuts and the often unfavourable consequences for the regeneration of several desired late successional species (Madsen et al., 2013).

Interestingly – and rather uniquely –non-native conifers today are not just grown in uniform even-aged plantation stands in Denmark, but are actively used as important tree species within the whole range of silvicultural systems and approaches – including close-to-nature forestry. This is not just happening in Denmark but in several European countries – but the extent of using non-native species in the whole range of silvicultural systems within the European lowland seems unique.

The key issues for the species selection are:

- does the tree species support the management objectives of the forest owner?
- is the tree species adapted to the site now and in the future?

- does the tree species regenerate sufficiently and naturally without becoming invasive?

Management objectives are very diverse among forest owners. Forest owners usually do not expect a return on their investments in forestry that can compete with the best investments on the financial markets. However, forest properties may serve as a stabilizing element of the investment portfolio of major – often institutional - investors. Although many forest owners may not expect much income from forestry, neither do they expect losses, and the amenity values of ownership, including rights to hunt, usually climb high up on the preference list of reasons for investing in forest.

Non-native species are integrated in the close-to-nature approach to forest management as long as they are used where they are adapted to site and can contribute to the formation of healthy continuous cover forest that later is capable of supporting natural regeneration of the desired tree species. Typical desired species among the non-natives with these characteristics are European and Japanese larch (*L. decidua* and *L. kaempferi*), Douglas fir (*Pseudotsuga menziesii*) and European silver fir (*Abies alba*). Additionally, species that may become invasive are avoided. As such, lodgepole pine and Sitka spruce may not be further introduced in some regions where close-to-nature forestry is used today depending on notably, the owner's preferences or strategies, certification standards or conservation regulations in protected areas. In other words, the species choice including the use of non-native species is today regulated by management goals and legislation with a wide range of practises at individual areas.

Advantages and disadvantages of non-native species

A number of forestry subsidy programs have been implemented particularly since the mid-1990s to support an increased use of native broadleaves – primarily by planting - to generally support the long term stability and biodiversity of forests. Subsidy programmes have often been revised annually both regarding their economic magnitude and the specific objectives and sites.

The capacity of several conifer species to facilitate the FLR-process by their tolerance to harsh conditions in the regeneration phase also made them popular in the forestry practises that followed the restoration process. In practise, they provided relative inexpensive regeneration on clear-cuts in forestry and together with their high productivity they remained popular species in the following forest generations. However, these aspects do not cover the full picture of their use. The Atlantic climate provides storms (gales) of sufficient strength to create severe forest damage by uprooting and breaking trees. Long-term statistics show that conifers – except larch that drop their needles in the autumn – are typically more prone to windfall than broadleaves. Exceptions occur when these storm appear relatively early in the fall (e.g. mid-October) and before leaf-fall. One of the consequences is that the application of shelterwood systems or any other system that involves thinning – including cutting gaps in the canopy - in even-aged conifer stands is too risky for most forest managers. The stand stability is considerably reduced by thinning – particularly strong thinning needed to create a shelterwood and open the canopy enough to allow the regeneration to develop. Besides, the conifers are generally viewed as less valuable contributors to forest biodiversity since they are not considered natural in the temperate forests of Denmark.

What is the relevance for today's FLR?

The Danish case has shown that what initially was very much based on the use of non-native species later created opportunities to reintroduce native species as well as other non-native species that may have desired functions. The key-point is that the species identified as desired species are fundamental for achieving the management goals. Firstly, this concerns the reclamation or revegetation process and later as forest generations pass and the ecosystem recovers the process develops more and more into what can be described as a rehabilitation process where mono-specific single-layered stand structures develop or are managed for a higher degree of complexity and/or species mixture (from plantation management to continuous cover silvicultural systems). As such, it is an example of how the process follows the restoration trajectory (Stanturf et al., 2014b) from a severely degraded stage towards a less degraded stage including ecosystem processes increasingly similar to those of a natural forest ecosystem. The species composition may not be exactly the same as in the natural ecosystem but the processes become more similar. The Danish case describes a functional restoration process that differs from a purely ecological restoration approach which would have emphasised native species only. Additionally, this process serves as an example of how much the productivity of forest landscapes can be increased from hardly any production capacity in degraded landscapes to very high levels by applying targeted silvicultural methods including appropriate choices of tree species.

Originally the great need for wood and increased productivity was the prime management goal when restoration was initiated – both to meet the needs of society and for the landowners and organizations who did the investments. Following the 2nd World War, Danish forestry experienced a very profitable period through the 1950s and 60s, which gradually faded away in the following decades making the business model of forestry resting on timber and biomass production less and less profitable.

Contemporary FLR

In the last decades, forestry profitability has been under pressure because of a general drop in prices of timber which reached a low around the middle of the first decade in the 21st century. Afforestation is, however, still taking place, but with a whole range of goals rather than the focus on land reclamation, revegetation and future production that were the main objectives 200 years ago. Further, the priority of these goals seems to change rather frequently over time.

There was not much afforestation implemented in the 1960s and 70s but it started again becoming an issue from the mid-1980s. Restoration sites were no longer degraded heathlands, instead they were now either conifer plantations to be further restored along the long-term restoration trajectory, or they were farmland sites targeted for afforestation. Therefore, it was no longer reclamation of severely degraded sites challenging young trees with unfavourable conditions that was on the table. The FLR efforts were now better classified as reconstruction – a process less challenged by abiotic thresholds compared to the early reclamation efforts. In the 1980s EU-subsidized surplus farm crops were viewed as a major problem, which sparked new governmental interest in afforestation to reduce farm crop production by reducing farm land areas. Another attractive goal was – at least as viewed in the beginning – to increase national timber production. The annual Danish wood consumption (8- 9 million

m^3) substantially exceeded the annual Danish harvest (2-3 million m^3) and greater self-sufficiency was seen as an advantage.

Moreover, the potential for more multifunctional forests and multiple ecosystem services delivered by forests attracted more and more attention. Pure conifer stands were still planted, but in 1989 the Danish government initiated a new afforestation program with the intention of doubling the forest area within one tree-generation (80-100 years). Timber production was still an issue, but ecosystem services such as nature conservation, biodiversity, recreation, carbon sequestration, bioenergy, and protection of environment and groundwater increasingly occupied a larger part of the agenda (Madsen et al., 2005). These were – and still are - common goals for forest management and FLR efforts in Denmark as well as in many other countries with or without afforestation programs.

What was new from the mid-1980s was the very limited focus on traditional forest products – primarily timber and pulpwood. Forestry experienced a deeper and deeper crisis rooted in a general trend of decreasing prices of wood – timber as well as pulpwood. The energy-wood market was established but the prices were very low. The values of forests for society and for private owners were more and more described by the multiple ecosystem services. For private land owners the returns on investments in forest and afforestation seemed more and more doubtful and relied increasingly on faith in the long-term nature of the investment involving elements like the forest's contribution to the pleasure of ownership ("I want to be a forest owner") and to the property value in general. Additionally, the value of hunting rights to all game species – that follow land ownership in Denmark – has shown increasing market values while the timber earnings have been under pressure.

Who does afforestation today and how much?

Existing major private forest owners have interestingly not contributed much to this latest wave of afforestation. Typical landowners who today do afforestation are often small – often part-time farmers – who make their income elsewhere or are retired – or it may be professional farmers who want part of their land to serve amenity values such as wildlife habitat and as hunting ground. Additionally, the state forest service and several municipalities as well as the cooperatively-owned water companies play a role in afforestation. The main afforestation aims of the state forest service and the municipalities are typically recreational purposes and development of future "natural areas" serving biodiversity purposes. Such afforestation projects usually are located near urban areas close to both relatively small towns and larger cities. The main aim for the water companies is to protect ground water resources and in several cases the state forest service contracts afforestation for water companies.

3. Achievements and outcomes

The recent National Forest Inventory (Johannsen et al., 2013) shows that the Danish forest area – according to the FAO forest definition – is 615,000 hectares, corresponding to 14.3 percent of the land area. Pure broadleaved and pure conifer forest cover each 41 percent and 39 percent, respectively, while 11 percent of the forest land is classified as mixed broadleaved and conifer forest (note that almost all of the conifer forest is non-native). The remaining areas are classified as areas of Christmas trees or decorative greenery as well as permanently or temporarily unstocked areas.

Schou et al. (2014) evaluated the recent (1990-2012) increase in forest area based on the National Forest Inventory data. The increase for the period was 69,000 hectares. There are significant afforestation subsidies available although these schemes are often changing in line with the slightly but ever-changing government goals for afforestation. However, the main part (84 percent) of the increased forest area has established without subsidies and of this 80 percent is on privately owned land (not including companies or foundations) while public afforestation is responsible for 12 percent. Much of this afforestation is probably not particularly intended and as such not aiming at the complete range of FLR objectives since it may simply be more or less abandoned areas like farmland on poor sites or inconvenient areas as well as Christmas tree plantings including those that are left to develop into forest following the last Christmas tree harvest.

According to Schou et al. (2014) close to 11,000 hectares have been subsidized whereas the Nature Agency that is responsible for the afforestation subsidies report an area of 18,600 hectares (Naturstyrelsen, 2015). The difference is probably caused by the fact that significant parts of subsidized afforestation projects include open habitats for recreational and biodiversity purposes and is as such not necessarily registered as forest by the National Forest Inventory.

Even including the expansion of the forest area by the more or less unintended new forest areas the government intention of doubling the forest area within one tree generation is far behind schedule. Fulfilling this aim would require an average 4,800 hectares new forest per year, but the expansion of the forest land has been 3,100 hectares per year. However, 64 percent of the new forest area is not protected against clearance contrary to the 72 percent of existing Danish forest area, which is under protection against land-use change.

In conclusion, the present governmental intention of doubling the Danish forest area within roughly 100 years starting around 1990 is far from reaching its target. The forest area is expanding at a pace that by first glance looks promising, but the main part of this is either unintended – and as such often not including many of the desired species or targeting completely other purposes than a comprehensive FLR-approach would do. Besides, it is not protected against future clearance and land use change.

4. Contributions to Climate Change Mitigation and Adaptation

Not only did the goals and objectives of particularly the recent (since the mid-1980s) forestry and restoration activities put much greater emphasis on multiple ecosystem services but considerable shifts in priorities have taken place, too. Firstly, there was the focus on reducing subsidized farm production within the EU in tandem with increased emphasis on the recreational functions of forests – of existing as well as of restored forests. Meanwhile, the interest in wood products almost faded away, while the recruitment of young people for forestry positions ceased and many experienced foresters were laid off or transferred to other functions than forest management within their organizations.

However, during the past 5-10 years forest productivity has gradually climbed back up the agenda. The Danish Government has set ambitious goals for decarbonizing the energy systems by 2050 and biomass is expected to play an increasing role in the future energy systems based entirely on renewables. Biomass – primarily woody biomass - is today the largest single component among the renewable energy sources and it is expected to maintain this position long into the future. The Danish energy policy is very much following the same goals as all of the five Nordic countries that have adopted strategies for decarbonizing their energy systems (Nordic Energy Research and International Energy Agency, 2013).

Today, wood represents half the biomass used for energy purposes. Consumption of wood in Denmark is approximately 18 million m^3 per year, of which about 20 percent comes from Danish forests (Graudal et al. 2013).

The use of biomass can both alleviate some of the climatic challenges the world is facing, as well as the expected increase in global demand for wood - but only if production is sustainable and utilization remains close to CO_2 neutral in the long run. Danish forests have the potential to increase self-sufficiency from about 20 percent to about 30 percent in 2050 if it is managed with increased respect for biodiversity and the environment at the same time as well as with a more intensive silvicultural approach at the productive part of the forest area. Assuming the intentions of expanding the forest area are met and other silvicultural measures such as genetic improvement and use of high-productive forestry systems are used together with expanding the non-intervention share of the forest area to 10 percent it is expected that the forests can contribute significantly to the Danish energy target of 100 percent renewable energy by 2050 and significantly more by 2100 (Graudal et al., 2013). Some key estimates indicate that the wood harvest can be increased by 30% by 2050 in tandem with a similar increase of the standing volume. Additionally, it is expected that the forests will be capable of increasing their share of energy production from 2 percent today of our total energy consumption to 7 and 13 percent in 2050 and 2100, respectively. The total carbon storage and fossil fuel displacement is further estimated be equivalent to less than 5 mio tons of CO2 annually today – but may potentially expand to 7-9 mio t and 10-13 mio t annually by 2050 and 2100, respectively, while at the same time contributing more to nature conservation and biodiversity objectives by increasing the forest area particularly dedicated to that purpose.

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Table 1. Summary of Danish restoration case study – describes the present situation from 1990 with emphasis on recent afforestation on farmland as well as rehabilitation of forest with higher proportions of stable, native and long-lived species.

In place	❋
Partly in place	⋆
Not in place	✕

Theme	Feature	Key Success Factor	Response
Motivate	Benefits	Restoration generates economic benefits	⋆
		Restoration generates social benefits	❋
		Restoration generates environmental benefits	❋
	Awareness	Benefits of restoration are publicly communicated	❋
		Opportunities for restoration are identified	⋆
	Crisis events	Crisis events are leveraged	⋆
	Legal requirements	Law requiring restoration exists	✕
		Law requiring restoration is broadly understood and enforced	✕
Enable	Ecological conditions	Soil, water, climate, and fire conditions are suitable for restoration	❋
		Plants and animals that can impede restoration are absent	❋
		Native seeds, seedlings, or source populations are readily available	❋
	Market conditions	Competing demands (e.g., food, fuel) for degraded forestlands are declining	⋆
		Value chains for products from restored forest exists	⋆
	Policy conditions	Land and natural resource tenure is secure	❋
		Policies affecting restoration are aligned and streamlined	⋆
		Restrictions on clearing remaining natural forests exist	❋
		Forest clearing restrictions are enforced	❋
	Social conditions	Local people are empowered to make decisions about restoration	❋
		Local people are able to benefit from restoration	❋
	Institutional conditions	Roles and responsibilities for restoration is clearly defined	❋
		Effective institutional coordination is in place	❋
Implement	Leadership	National and/or local restoration champions exist	❋
		Sustained political commitment exists	⋆
	Knowledge	Restoration "know-how" relevant to candidate landscape exists	❋
		Restoration "know-how" transferred via peers or extension services	❋
	Technical design	Restoration design is technically grounded and climate resilient	⋆
	Finance and incentives	"Positive" incentives and funds for restoration outweigh "negative" incentives for *status quo*	⋆
		Incentives and funds are readily accessible	⋆
	Feedback	Effective performance monitoring and evaluation system is in place	✕
		Early wins are communicated	❋

Table 2. Summary of mitigation and adaptation potential – Danish case study situation from 1990 with emphasis on recent afforestation on farmland as well as rehabilitation of forest with higher proportions of stable, native and long-lived species.

Mitigation/ Adaptation/ Transformation	Objective	Mechanism	Restoration Activity	Implementation Level
Mitigation	Sequester carbon	Increase forest area	Afforestation	❋
		Increase biomass/unit area	Increase productivity of timber and biomass	⋆
			Longer –lived species and higher standing carbon stocks	❋
		Increase soil carbon	Increase rooting depth and below ground carbon	⋆
	Reduce emissions	Bioenergy	Nurse crops used to favour establishment of late successional species and to create early harvests	❋
Adaptation	Maintain forest area	Reduce deforestation drivers	Deforestation has ceased long ago - any reduction of the protected forest is compensated by larger area of afforestation elsewhere	❋
		Reduce degradation	Most of the forest area is strictly protected as forest land – land use change is not an option	❋
	Maintain carbon stocks	Reduce degradation	Sustainable forest management – including improvement of forest productivity and stability	❋
	Maintain other forest functions	Improve biodiversity	Afforest with mixed species and higher proportion of native species including shrubs and light demanding tree species.	❋
			Protecting key habitats, leaving standing and fallen dead wood as well as leaving forest without intervention and managing for biodiversity through certification standards	❋
			Restore microsites and natural hydrology, ponds and lakes by reducing or ceasing maintenance of drainage systems	❋
			Use of pesticides avoided or restricted	❋
			Establishment or maintenance open habitats by grazing and/or mechanical methods	❋
			Manage for species of concern by	❋

			protecting habitat types through former protection declarations or the EU Natura2000 Habitat Directive	
		Improve hydrology	Restore microsites and natural hydrology, ponds and lakes as well as reduce maintenance of drainage systems	❋
			Deforested stream buffers are in Denmark surprisingly often viewed as a desirable status from both biodiversity and landscape aesthetics perspectives	×
	Manage for resistance	Reduce vulnerability to stressors	Integrated pest management by e.g. removal of timber trapping bark beetles	★
		Overcome regeneration barriers	Secure regeneration by fencing or using planting and direct seeding - sometimes combined with natural regeneration	★
		Reduce vulnerability by expanding the genetic variation	Continue working with introduced species, provenances and improved genetic material in general	❋
	Manage for resilience	Expand population (within range)	Emphasize site-adapted and long-lived species – native as well as non-native. Reduce use of species that are known for poor stability, short-lived or expected poor adaptation to future climatic conditions.	❋
		Expand range	Species choice to secure adaptation of species to site –introduce or support use of more species or provenances	★
		Create refugia	Unmanaged forest	❋
Transformation	Novel ecosystems	Manage spontaneous ecosystems	Management of mixed species forests – supported by both subsidy schemes for afforestation and forest rehabilitation.	❋
		Create ecosystems	Translocate species - our country is too small to distinguish between translocation and introduction on non-native species	★
			Replace species within assemblages with desired functional traits	❋
			Introduce exotics (non-native species) with desired functional traits	★