Interference pathway of power transmission and transformation project on ecosystem

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Abstract. Understanding the interference pathways of power transmission and transformation projects on ecosystem is an important basis for the meticulous implementation of ecological protection. In this paper we analyze the interference characteristics of the projects and discern what the interference pathways are on different ecosystem in two periods of construction and operation, including forest ecosystem, grassland ecosystem, wetland ecosystem, desert ecosystem and farmland ecosystem. After the analysis, some protection and restoration measures are put forward. The results show that the main interference factors are building towers, power stations, doing earthing electrodes during construction period and activities of monitoring, management and maintenance during operation period. For different ecosystems, the interference pathways are variant, so discrepant measures should be taken to different types of ecosystems.

1. Introduction
In recent years, China's economy has developed rapidly with strong demand for electricity in society [1]. From 2010 to 2015, the annual average electricity consumption per capita in China has increased by 5.75% annually, exceeding the world average level of about 2.2%. By 2020, it will reach the level as the moderately developed countries have. Continued growth in electricity demand, combined with a large amount of clean energy supply we need today to tackle haze weather, has led to the planning and construction of a large number of ultra high voltage direct and alternating current transmission projects(UHVDC/UHVAC) in Chinese state grid system in recent years, which will inevitably bring about impacts on the ecological environment along the line. Therefore, it is necessary to systematically evaluate those ecological impacts. Related laws and regulations characterize the technical procedure of evaluating impact where an important section is indentifying overall interference pathways. But, it is new to focus on types of ecosystems. Each type of ecosystem with distinctive eco-elements may give their response to interference from different pathways. By comparison study and summary of interference pathways on different ecosystems, the ecological impact mechanism of power transmission projects can be furthur clarified, which would help support the prediction of ecological impacts better and provide more reference for designing routes, selecting sites and screening the ecological protection technologies.combined with evaluation results.

At current, related researches have finely disussed EIA standards, laws of construction projects. Zhao Y[2] indicated that EIA laws and regulations covers many laws such as Environmental Protection Law (amended in 1989), Wild Animal Protection Law (1988), Land Administration Law...
(Amended 1998), Environmental Protection for Construction Projects (SEPA, 1990), Administrative Procedure of Environmental Protection for Electromagnetic Radiations (SEPA, 1997), etc, which are consists of the EIA laws system and announce abundant strict requirements on recognizing, evaluating and mitigating environmental impacts. Ecological impacts assessment are important content of EIA, so identifying interference pathways on kinds of ecosystems is significant. However, for natural forests, grasslands, wetlands, deserts, farmlands or other ecosystems, fewer studies have been made. Some researches focus on electromagnetic environment interference [3] and the impact about electric shock accidents on birds [4], they based on experimental statistics and find out soil ecology and birds population ecology can be affected. Other methods to identify the interference pathways conclude GIS overlay analysis, numeration method and factor classification method Wei T [5] calculated the change of landscape index caused by power transmission and transformation projects, then analyzed the change rule of landscape structure, by which he clearly proposed that the interference pathway on landscape structure comes from permanent land occupation. Ping Y’s group [6] summarized and listed the impact factors of transmission and transformation project, then by qualitative method they identified five main factors which includes direct disturbances on the natural environment, electromagnetic field, transmission noise, waste water discharge and maintenance activities of personnel. And then, they concluded that different interference pathway runs differently. Unlike current research status, relevant Environmental Impact Assessment (EIA) application has been carried out more often. EIA reports contain more descriptions of interference pathway, where qualitative analysis method is mostly used based on land use interpretation, vegetation and animal ecological survey, to identify and enumerate impacts from several aspects like the vegetation, animals, landscape fragmentation and so on. In general, both the current researches and application lack systematicness and ignore studying the differences of different ecosystems when identifying the interference pathway. So most results are difficult to fully reflect the characteristics of the impacts on typical ecosystems and thus cannot provide a solid foundation for site selection and impact prediction.

This paper systematically explores interference pathways of power transmission and transformation projects in two periods of construction and operation as well as in different types of ecosystems, then discuss the differences between five types of ecosystems by comparative analysis. On basis of our results, we propose some practical mitigation measures at final.

2. Interference characteristics of power transmission and transformation projects on ecosystem

The interference of transmission and transformation projects has the following four main characteristics:

(1) Discontinuous-linear interference.

The power transmission and transformation project is a special type of linear construction project [7]. Since transmission lines lie in the air, the towers which support and connect the lines make it the main land-occupied part of the project along the line. As it is, its linear effect is non-continuous and in dotted distribution, which, compared with the road, railway or other typical linear construction, has some differences.

(2) Cross-regional interference

The length of great power transmission and transformation project is up to thousands of kilometers, and along the line there are diverse topography and complex ecological conditions. Most projects therefore cross a variety of ecosystems, with a variety of interference receptors that contribute to various interference pathways.

(3) Forming Comprehensive impact easily

The internal elements of ecosystem are interrelated through the process of material exchange and energy flow. There are direct and indirect interference on ecosystem during construction period, and all the interference takes effect in company, which easily results in the comprehensive impact on different components of the ecosystem.

(4) Interference mainly coming from construction period
There are different types of ecological interference with different origins during construction and operation period, so the interference pathways vary a lot in different periods. In construction period the types of ecological interference are richer and the intensity of them are higher compared to those in operation period, thereby making the construction period as the project phase with dominant interference.

3. Interference pathway and impact during construction period

3.1. Interference pathway and impact on forest ecosystem

Forest ecosystem is a kind of natural complex with certain structure, function and self-regulation formed by function flow of forest community and environment. It is the largest and most biodiverse ecosystem with the most complicated community structure among terrestrial ecosystems. Transformer substations, converter stations and towers of the project are designed to avoid occupying lands as little as possible in the forest ecosystem, which is good to reducing the ecological impact of power transformation and transmission projects [8]. However, the construction must have some permanent or temporary land, leaving the plants, animals and habitats of forest ecosystem suffering long-time impact.

For plants, it is required that the vertical distance between the submarine trees and the lines be less than 4.5m in order that lines run well, but cutting these trees brings destruction of vegetation and reduction of plant diversity [9]. In the process of construction, vegetation are cut down or trampled to death by building makeshift roads, operating machinery, personnel’s living in construction camps and other activities. The construction of tower clears a certain area of trees, shrubs and herbs, resulting in degradation of vertical structure, reduction of population density of dominant species, reduction of biomass, disappearance of sensitive species, reduction of biodiversity and productivity of forest ecosystems. Soil excavation cause soil structure destruction, damaging the function of soil and water conservation, which may interferes with forest health indirectly. The dust and industrial harmful gas, which are produced during construction, can affect the photosynthesis and transpiration of plants, and then plants get damaged indirectly and forest ecology go worse. It is possible that exotic species are brought in along with materials carried to construction area, which is a big threat to native species. If the exotic species hold the niches because of their advance in competition, it will change the species composition. Generally, project construction causes a small-scale interference on forest vegetation, such as damaging the canopy structure, changing the species composition and so on. However, the forest succession period is long due to the life history characteristics of trees, and it is a long-time work to complete the forest restoration, so the impacts on forest vegetation is chronic, obvious and bad.

The plant communities in ecosystems provide food source and nesting space for animals. Therefore, clearing and destroying the plant communities on the ground will make some direct and indirect interference on higher trophic-level animals through cascade effect of ecosystem, especially on birds. The construction of projects interferes with animal activities, mainly including inhabiting, foraging and breeding. Birds that live on trees lose their nest after cutting trees down, which decrease the vegetation coverage, thereby making birds get exposed to enemies and preys easily. The workers who destroy the nest, picking up eggs or hurting young birds when they use machinery during construction period will also directly affect the success rate of bird breeding. Dust, garbage, gas pollutants, etc, produced during construction also bring bad effect on other animals. The increase of garbage accumulation in forest habitat and the discharge of construction and domestic sewage can worsen the forest animal habitat, affecting their inhabiting, breeding and foraging. Noises of construction drive forest animals to other places, affecting the animal regular outside activities [10]. These impacts are mostly short and reversible, with construction phase finished, they will disappear gradually.

The construction also affects the soil environment. There are multiple processes rolling or turning over the soil that includes tower erecting, land leveling, foundation excavation, wires installation, etc. Owing to the centralized construction area, long-term construction period and massive heap of materials, the structure of soil in construction area get destroyed, contributing to water loss and soil
erosion which affects soil fertility. Soil erosion caused by subgrade filling and out-of-time slope protection also affects soil texture in construction site [11]. Moreover, soil pollution and other environment problems can be brought about by spoil, residue and garbage.

In conclusion, the construction phase has varying degrees of impacts on vegetation, animals and soil in forest ecosystems. Most of these impacts in construction period are reversible, but restoration of forest ecosystems takes a long time.

3.2. Interference pathway and impact on grassland ecosystem
Grassland is one of the most important types of terrestrial ecosystems on earth. It is a perennial plant community that is drought-tolerant, cold-resistant and grass-dominated, with rich flora and fauna. The main impact factors in grassland ecosystem in construction are land occupation of converter stations, substations and towers, and the secondary factors are workers’ construction activities, passing of vehicles, mess of earthwork, etc.

Permanent occupation of land leads to a decrease in grassland area, which directly causes permanent loss of biomass and productivity, bringing about a small range of species composition and biodiversity change. Dust generated in construction and harmful gases discharged by machinery affect the photosynthesis and transpiration of grassland vegetation and then grassland productivity get affected indirectly [12]. During construction, workers’ activities like daily living and machine using may trample and damage grass vegetation. The clutter of garbage or disorderly-disposed earthwork occupy grassland that will destroy the herbal resources, so it may affect the community succession of grassland ecosystem, and then indirectly affecting the grassland species composition, biodiversity and stability of ecosystems [13] Constructing in areas with dry climate, fire is prone to happen if there’s weak fire prevention awareness and management, which can cause greater damage to grassland resources [14]. Most of this interference is indirect, short-term, and reversible.

There are not many birds in the grassland generally but where mammals and cave animals are dominant. So it is mammals and cave animals that are affected more by the construction [15]. The projects occupy part of grassland, resulting in reduction of grassland area, destruction of grassland vegetation and the fragmentation and degradation of grassland habitat. Thus, the foraging and reproduction of herbivorous organisms are affected, as an indirect impact on the daily activities of animals [16].

The improper use of machine or other uncivilized behavior of the builders can affect the grassland habitat. Doing earth excavation and filling it with spoil directly destroy the soil structure and soil fertility of grassland [17]. Waste debris piled up, habitat quality will face a decline; workers’ trampling optionally, vegetation will be badly damaged; construction equipment rolling and compacting the earth, soil density and texture of grassland will get changed, making impacts on soil development as well as soil fertility. These impacts have direct and short term effects, after construction, the disturbed grassland can be gradually restored nearly as it was.

Therefore, during construction period, plants, animals and soil in the grassland ecosystem will be affected to different extents. Habitat, population density, biomass and productivity of grassland ecosystems will be directly affected by short-term, adverse impacts, and species composition and diversity will be affected indirectly and adversely.

3.3. Interference pathway and impact on dessert ecosystem
The desert vegetation is sensitive, fragile and relatively sparse with rather weak productivity, but plays an important role in providing food and shelter for desert animals, participating in energy transformation and material circulation in dessert ecosystem, preventing wind erosion and fixing quicksand, etc [18].

The most direct interference on dessert ecosystem is tower and power station of which the land occupation brings about destruction of vegetation and disturbance of soil. Permanent occupation clear out the vegetation within the occupied area, which can directly cause the permanent degradation of biomass and productivity. During construction, workers as well as vehicles passing in and out,
temporary stacking of materials, piled-up earthwork all will trample, roll and compact dessert vegetation [19]. For the reason that the self-recovery ability is pretty poor and inner structure is rather simple, when being destroyed in a large scale, it will be a serious problem that soil erosion intensify and foraging of dessert animals is at risk with a hard recovery in short period of time. In this sense, these impacts on dessert are strong and long-term. But, there used to be not much impact on animals when projects are constructed in this area because the density of dessert animals is small and they have good migratory aptitude to avoid disturbances [20].

3.4. Interference pathway and impact on wetland ecosystem

The wetland ecosystem is mainly distributed in the lakes, reservoirs, rivers and their sides [21]. Wetland is a transitional area between land ecosystem and aquatic ecosystem where soil is under a soaking environment, and there are many wetland plants and plenty of wildlife resources, which is one of the most important ecosystems.

During the construction period, the most direct impact is soil erosion caused by land occupation and constructive activities. It will lead to a small range of removal of wetland vegetation if erecting tower on wetland, which is to make the permanent reduction of wetland community biomass. When slope protection is not timely done, soil erosion will take place easily, transporting a large amount of sediment, nitrogen and phosphorus into waters so that water turbidity increase and water quality get affected [22]. The discharge of sewage of substations in construction directly pollutes the wetland water and affects the habitat of aquatic organisms [23] and then indirectly affects the survival of wetland plants and animals, destroys the species composition, reduces the stability and productivity of wetland and affects the ecosystem services like wetland purification capacity. Permanent or temporary land occupation can directly destroy the habitat of wildlife. The construction noises as well as lights used in the evening can hinder animals from good sleeping, easeful inhabiting and successful breeding, with which the habitat gets worse and indirectly lead to a decline of biodiversity of wetland ecosystem. Despite that these impacts is somewhat strong, they won’t exist too long. After construction, the impacts strength will meet with a sharp decline, nearly to none.

3.5. Interference pathway and impact on farmland ecosystem

Farmland vegetation, as one of the cultivated vegetation, is with simple community structure and mostly single species composition. Generally, the construction of projects makes impacts on farmland ecosystem mainly by pathways of affecting the area of farmland, crops biomass and productivity, and soil environment.

Earthwork excavation and land occupation of towers eliminate the occupied crops that its yield will go down. The accumulation of soil and stone debris after excavation and using construction machine or tools can damage crops and theirs root systems, interfering with the normal growth of crops. Thus, productivity of the whole farmland ecosystem falls consequentelly. These above impacts are short-term and reversible. In addition, the excavation of the foundation will directly destroy the tillage layer of the soil, and after mixing and backfilling the earthwork, the soil structure, texture and compaction changes, thus affecting soil fertility, nutrients and tillage performance [24]. On this condition, the growth of crops and productivity of farmland will be indirectly affected. These impacts are intense and take long time to recover. Besides, if towers stand on farmland, it will have impacts on the farming and harvesting of agricultural crops during the harvest period, which is to be long-term and even irreversible.

4. Interference pathway and impact during operation period

4.1. Interference pathway and impact on forest ecosystem

During operation period, the major impacts comes from permanent land occupation, transmission lines, noises of power station and high-voltage electromagnetic field, which can make slight but long-term
impacts on wildlife animals [25]. Additionally, regular operation, maintenance and management activities of operators are important factors that have long time to affect forest ecosystem.

In order to keep the normal operation of transmission lines, the trees whose canopy reach the height that is 7m lower or less than lines’ should be regularly pruned [26]. If pruned improperly, the trees’ canopy will be ruined by structural change, and the superiority of tree layer will be impaired, thereby influencing species composition and species density indirectly. Operators use fire and smoke may accidentally burn out the forest vegetation, making the biomass and productivity suffer heavy decline. Birds are mostly likely to contact the lines, which sometimes cause their death by electric shock. The operation period will therefore have indirect impact on the biodiversity and stability of forest ecosystem.

4.2. Interference pathway and impact on grassland ecosystem
For grassland ecosystem, the major impacts are from permanent land occupation and operational activities. Between the two, the former occupies grassland resources, leaving direct, long-term and adverse impacts; the latter may hurt root and stem of herbs, destroy the above-ground plants community, and leave a certain disturbance to the small terrestrial animals. These impacts are direct, temporary, and hard to recover. However, the grassland soil environment will be nearly non-affected. In this period, habitat quality will not change much, species diversity may be changed slightly during community succession, thanks to the permanent land occupation which brings the disturbance of species composition and density.

4.3. Interference pathway and impact on desert ecosystem
The most direct impact on desert in this period is also caused by permanent land occupation. Regular monitoring, overhaul lines, trampling and other activities may have a direct and short-term impact on desert vegetation. But the desert vegetation is sparse, vegetation are not strongly interfered in large amount, so the species composition and diversity are almost unaffected. Similarly, the effects on species density, biomass and productivity are also faint. Although, there are little impacts, because of the poor self-recovery capacity of the desert system, these small effects can also be long-term.

4.4. Interference pathway and impact on wetland ecosystem
With regard to wetland ecosystem, the monitoring and maintenance activities are most likely to affect the ecology. Aquatic plants can be damaged by people’s trampling or other man-made disturbances, also, noises and lights used by people directly affect the comfort of wetland habitat, making part of wetland animals not adapted to it and go into abnormal state of inhabiting, breeding and so on[27]. On condition that people bring in disturbance, the wetland will have impacts on biodiversity, productivity and population density, and these impacts are long-term but not that strong.

4.5. Interference pathway and impact on farmland ecosystem
The most important impact comes from land occupation of projects, in that occupied farmland cannot be cultivated as ever. The area of farmland get a decrease, and even help to bring about change of cultivation method and crops type, which indirectly change species composition and planting density. Soil tillage layer, compactness, texture and fertility are not obviously affected, so the crops productivity and biomass are not expected to be under big pressure.

5. Mitigation measures based on interference pathway recognition
Through reviewing relevant studies, it is found that in all types of ecosystems, interference pathways mainly conclude habitat (soil environment), species composition, biodiversity, population density, biomass and productivity. On basis of above elaboration, an identification matrix is made as a summary to show characteristics of different interference pathways in the five types of ecosystems and in two periods of construction and operation. This characterization is followed symbolic representation method [28], which is widely used and applied in Chinese EIA reports.
Results in table 1 imply that direct and short-time impacts are almost generated from construction period, while indirect and long-time impacts are more likely from operation period. For forest ecosystem, it is different in that during either construction period or operation period all the interference pathway are in forms of long-time impacts and for dessert ecosystem, long-time impacts are preponderant. For farmland ecosystem, impacts are neither positive nor adverse.

On the whole, all ecosystems get interference mainly by permanent land occupation. In order to reduce the impact of land occupation on each ecosystem, it is suggested to focus on ecological protection more in the phase of line selection to clarify the basic laws and regulations and minimize occupation of land use which is with high ecological value and high ecological vulnerability. Secondly, irrational construction methods may also cause damage to the ecosystem. For this, we suggested that education and training be strengthened to encourage construction personnel to strictly abide by the regulations and devote to civilized construction to form a good atmosphere of mutual supervision. Moreover, construction workers are required to implement the principle of excavation and filling balance and properly handle earthworks [29]. Meanwhile, in order to mitigate the long-term impacts on vegetation and animals, it is suggested to strengthen ecological restoration and animal protection in the later period, strictly carry out replanting and tending work and other measures to restore vegetation in time, regularly observe injured animals by electric shock and timely give help.

Table 1. Identification matrix of the interference pathway and impact of transmission and transformation projects.

| Content                  | Habitat(Soil Environment) | Species Composition | Biodiversity | Population Density | Biomass | Productivity |
|--------------------------|----------------------------|---------------------|--------------|--------------------|---------|--------------|
| Forest ecosystem         | Construction period        | ▲-2L ▲-2L ▲-2L ▲-2L | ▲-2L ▲-2L ▲-2L | ▲-2L ▲-2L ▲-2L | ▲-2L ▲-2L ▲-2L |
|                          | Operation period           | △-2L △-2L △-2L △-2L | △-2L △-2L △-2L | △-2L △-2L △-2L | △-2L △-2L △-2L |
| Grassland ecosystem      | Construction period        | ▲-2S △-2S △-2S △-2S | ▲-2S △-2S △-2S | ▲-2S △-2S △-2S | ▲-2S △-2S △-2S |
|                          | Operation period           | ▲-2L △-2L △-2L △-2L | ▲-2L △-2L △-2L | ▲-2L △-2L △-2L | ▲-2L △-2L △-2L |
| Wetland ecosystem        | Construction period        | ▲-2S △-2S △-2S △-2S | ▲-2S △-2S △-2S | ▲-2S △-2S △-2S | ▲-2S △-2S △-2S |
|                          | Operation period           | △-2L △-2L △-2L △-2L | △-2L △-2L △-2L | △-2L △-2L △-2L | △-2L △-2L △-2L |
| Dessert ecosystem        | Construction period        | ▲-2S ▲-2L △-2L △-2L | ▲-2L ▲-2L △-2L | ▲-2L ▲-2L △-2L | ▲-2L ▲-2L △-2L |
|                          | Operation period           | ▲-2L △-2L △-2L △-2L | ▲-2L △-2L △-2L | ▲-2L △-2L △-2L | ▲-2L △-2L △-2L |
| Farmland ecosystem       | Construction period        | ▲-2S △-2L △-2L △-2L | ▲-2S △-2L △-2L | ▲-2S △-2L △-2L | ▲-2S △-2L △-2L |
|                          | Operation period           | △ 2L △ 2L △ 2L △ 2L | △ 2L △ 2L △ 2L | △ 2L △ 2L △ 2L | △ 2L △ 2L △ 2L |

Note: “▲” refer to direct impacts, and “△” refer to indirect impacts; “+” refer to positive impacts, “-” refer to adverse impacts; “1” refer to single impacts, “2” refer to combined impacts; “L” refer to long-term impacts, “S” refer to short-term impacts.

For forest ecosystems, reduce the felling of trees, use gaps to erect the tower, avoid constructing in the peak time of forest wildlife activities, and avoid using night lights which interfere with forest wildlife [30], additionally consider to follow the seven Holford Rules [31] to prevent forest landscape impacts. For grassland ecosystems, reduce the trampling and compaction of high-covered grassland, reduce damage to grassland vegetation, prevent trapping for grassland reptiles, try to avoid unnecessary soil erosion caused by construction in high-slope areas; For wetland ecosystems, avoid building towers in wetlands and on water, reduce the scope of construction, do not carry out large-scale excavation around the wetlands, set up warning signs and educate construction workers not to do fishing, not to throw dirty things into the water and not to damage the wetland aquatic ecology [32]. For desert ecosystems, make sure the construction camps are set up in bare land or wasteland where the vegetation is extremely sparse, as well as construction materials are stacked in an orderly manner.
and the domestic garbage is handled properly in time. For farmland ecosystems, erect the tower on the field path or between fields, when it is unavoidable to do it in the field, try to erect high-foot tower, reducing the loss of farmland and decline of agricultural production.

6. Conclusions
Power transmission and transformation projects have four characteristics in ecological impact that is discontinuous-linear, cross-regional, comprehensive, and mainly from construction period. These projects mainly affect the habitat conditions, species composition, density and biodiversity in different ecosystems and further to reduce their biomass and productivity, thereby resulting in comprehensive impact on the stability and health of ecosystem. The interference pathway of different ecosystems such as forests, grasslands, wetlands, deserts and farmlands are significantly different from each other, and compared to operation period, construction period is when the impact pathways are more and impact intensity are higher. The impacts are mainly direct and short-term during construction period whereas those of operation are mainly indirect and long-term. In order to mitigate the ecological impact, for all types of ecosystems, we should give priority to the selection of low-ecological-value land, and strengthen education and ecological restoration in the later period. For forest ecosystems, choose the canopy gap and the forest margin to erect towers to reduce the felling of trees as well as disturbing the wildlife and strictly follow the Holford Rules; for grassland ecosystems, reduce the compaction of the grassland and the destruction of the turf and prohibit the hunting of grassland animals; for wetland ecosystems, avoid erecting towers in waterways and fishing must be forbidden; for farmland ecosystems, it is better to make tower on the field path or adopt high-foot tower.

Symbolic representation method used in this paper shows advantage in identifying interference pathways. Not only does it fuse reviewing results into each symbolic expression, but also make it handily to make lateral and longitudinal contrast of interference characteristics. This procedure is surely served for accuracy of ecological impact prediction.

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