International Journal of Systems Engineering
2021; 5(2): 79-89
http://www.sciencepublishinggroup.com/j/ijse
doi: 10.11648/j.ijse.20210502.14
ISSN: 2640-4222 (Print); ISSN: 2640-4230 (Online)

A Natural Sequence of Socio-Technical Transition Pathways

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To cite this article:

Mohammed Hussaini, Miklas Scholz. A Natural Sequence of Socio-Technical Transition Pathways. *International Journal of Systems Engineering*. Vol. 5, No. 2, 2021, pp. 79-89. doi: 10.11648/j.ijse.20210502.14

Received: November 19, 2021; **Accepted**: December 7, 2021; **Published**: December 24, 2021

Abstract: This paper provides a simplified analysis of possible sequences of transition pathways to deepen understanding of transition scenarios. The pathways exhibit a ranking of succession in which the transformation pathway (T) is first in the sequence in terms of both landscape pressure (P_L) and niche maturity levels (γ_n). The next pathway along the sequence in terms of the two variables of P_L and γ_n is the reconfiguration pathway (R). Beyond R, the substitution pathway (S) is significantly higher in terms of γ_n whereas the de-alignment/re-alignment pathway (D/R) is significantly higher in terms of P_L. The next pathway on the sequence among the two pathways, namely S and D/R depends on the difference in the rates of change of P_L (i.e. P_L/t) and γ_n (i.e. γ_n/t) and the P_L difference of D/R to R ($P_{L.D/R} - P_{L.R}$) and the γ_n difference of S to R ($\gamma_{n.S} - \gamma_{n.R}$). A higher P_L/t to γ_n/t and/or a shorter $P_{L.D/R} - P_{L.R}$ to $\gamma_{n.S} - \gamma_{n.R}$ support the sequence T-R-D/R-S whereas a lower P_L/t to γ_n/t and/or a larger $P_{L.D/R} - P_{L.R}$ to $\gamma_{n.S} - \gamma_{n.R}$ favours T-R-S-D/R sequence. In the case of equivalent $P_{L.D/R} - P_{L.R}$ and $\gamma_{n.S} - \gamma_{n.R}$, and also P_L/t and γ_n/t, then beyond R, a fifth scenario (X) which combines part characteristics of both D/R and S has been discussed. In view of deviations from this assumption in theory, changes in P_L and γ_n (and hence X) might not be linear and is determined by the slope $\delta P_L/\delta\gamma_n$ while the status of X with respect to D/R and S at any time depends on its parametric proximity with respect to D/R and S at that time. Moreover, P_L/t in turn depends on the pathway history of a transition whereas niche maturity γ_n is affected by transition policy action which improves the overall performance-cost ratios of niche (γ_n) and regime (γ_r) technologies, γ_n/γ_r. However, in all the case, there is the need to establish accurate measurements for P_L and γ_n and for the pathways to enhance the certainty of the pathway sequence.

Keywords: Graphical Presentation, Landscape Pressure, Multi-level Perspective, Niche Technology, Pathway Sequence, Regime

1. Introduction

Transitions are initiated by landscape development and driven by complementary changes at all the three levels; landscape, regime and niche levels [1, 2]. Landscape pressure exerts its weight on regime, destabilizing it to form cracks or windows of opportunities where niche contents (new innovations) pour in. With time, these new introductions (niche elements) into the existing regime form part or whole of the new regime. The pathways to these changes depend on the measure of the landscape and niche developments levels at the point of landscape action (at the start of transition), which determines the type of system change that will be involved. Since changes at both landscape and niche levels with respect to transitions are forward oriented, a possible sequence for the pathways can be defined in the same orientation. Geels and Schot [3] indicated that the possible sequence of the four transition pathways is either T-R-S-D/R (Transformation-Reconfiguration-Substitution-De-alignment/Re-alignment) or T-R-D/R-S depending on a number of factors relating to landscape pressure P_L and niche maturity γ_n beyond R. This paper builds on this notion by advancing discussions on the concept of the alternate sequences and outlining the determinants of the sequence of transition pathways.

The aim of this paper is to elaborate the characteristics of the pathways, outline the factors which determine the pathway sequence and simplify their presentation. The first objective is to describe in more details, the different transition phases of the pathways, their advantages and disadvantages based on literature. The second objective is to provide a ranking of the dynamics in the four transition pathways namely; transformation (T), reconfiguration (R), substitution (S) and de-alignment/re-alignment (D/R) while outlining the determinants of pathway position in the sequence. The third objective will be to provide graphic illustrations of the relationships between landscape pressure development, niche development and regime changes (transitions). The purpose is to study the successive linkage of socio-technical transition pathway scenarios assuming the drivers of change have been established. Therefore, a mere mention of 'technology emergence' will also mean its emergence in association with the relevant actors and rules/institutions. The reproduction pathway is not included in the analysis because it is always in existence even in the absence of a disruptive landscape pressure (Rosenberg, 1982, cited in [3]).

The paper is structured as follows; Section 1 introduces the subject matter, highlighting the aims, objectives and contributions of the paper. Section 2 gives a brief of transition literature reflecting on a conceptualisation of the emergence of socio-technical transitions. It also introduces the types of system change and the different phases involved in transitions. Section 3 provides a description of the socio-technical transition pathways. Section 4 draws analysis and provides discussion of the characteristics of the transitions pathways, including advantages and disadvantages and pathway sequence. Based on these, a graphical illustration of the pathways has been designed which simplifies the conceptualisation of the pathway sequence. Section 5 provides conclusions on the determinants of pathway sequence, the significance of the sequence and recommendations on further works necessary in enhancing the accuracy of the sequence.

2. Socio-technical System Transition

According to Rotmans et al. [4] "Transitions are transformation processes in which society changes in a fundamental way over a generation or more" or in other words, transition is "a gradual, continuous process of change where the structural character of a society (or a complex sub-system of society) transforms." System transition is the outcome of interconnected developments in the various domains and elements of a system which include technology, policy, science, economy, ecology, institutions, practice, culture etc [5]. Actors and special interest groups include policy makers, companies/industries, civil society, consumers, engineers and researchers [6]. Consequently, these domains and elements may be grouped into two broad components or subsystems; the social and technical subsystems to give a socio-technical system. Thus, the socio-technical approach to transitions conceptualises a system as a composition of social and technical elements which emerge in a co-evolutionary manner (Rip and Kemp, Geels, Hoogma et al., cited in [7]). In simple terms, socio-technical system transition can be defined as a structural change in both the technical and social subsystems of a system [8]. Figure 1 below shows a socio-technical system with transition (system A-B) and without transition (system A-A) over a certain period of time. The scale of transition or regime change is one important consideration in socio-technical transitions.

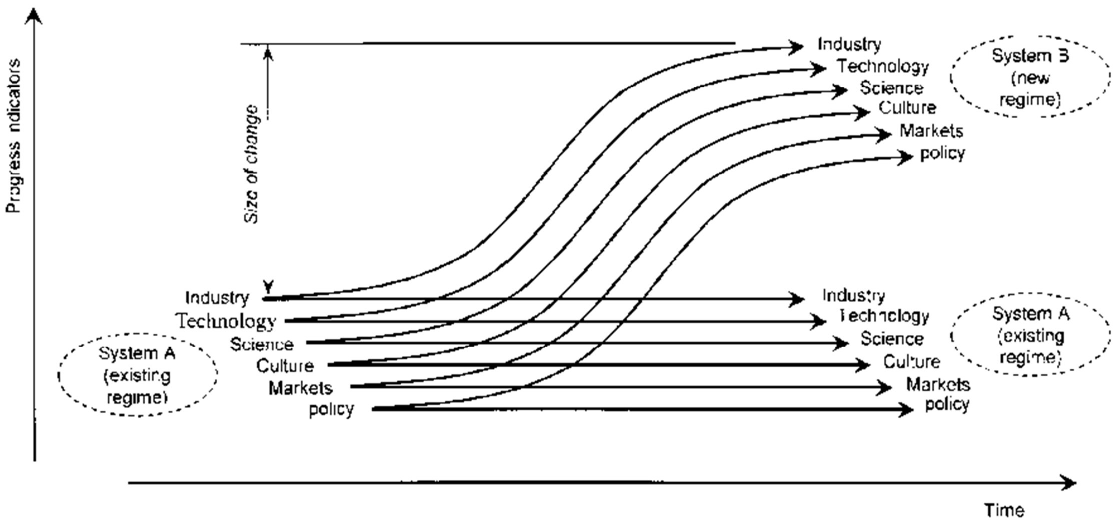

Figure 1. *Socio-technical system with and without transition.*

2.1. Types of System Change

The types of system change involved in socio-technical system transitions include:

1. *Incremental change*: This type of change is the most common and involves updating or improving existing systems – competence enhancing. An incremental change is solely based on existing technologies or processes [9].
2. *Modular change*: Modular change is a significant improvement within a system without changing the basic architecture of the system [10, 11].
3. *Radical change*: A radical change is one that substantially involves new technology which normally would not conform to existing system because it introduces new technologies and practices which are radically different from the antecedent [12]. Radical innovations are usually confined to niches in the absence of huge landscape pressure because they tend to have a competitive relationship with the incumbent regime [3].
4. *Architectural change*: Architectural change occurs when radical innovations change the existing correlation between technical (nodes and links) and non-technical elements of the system, i.e. the network architecture or value network [13]. Such innovations are often a threat to sunk investments and embedded competencies and as such are always controversial and take a long period of intense competition before emerging [14].

2.2. Phases of Transition

Four transition phases can be identified in transition pathways as shown in Figure 2 [4]:

1. A *predevelopment phase* is one of dynamic equilibrium.
2. The *take-off phase* where change starts to occur;
3. A *breakthrough phase* in which visible structural changes take place;
4. The *stabilisation phase* which marks the end of transition, where speed of change decreases and a new dynamic equilibrium is reached.

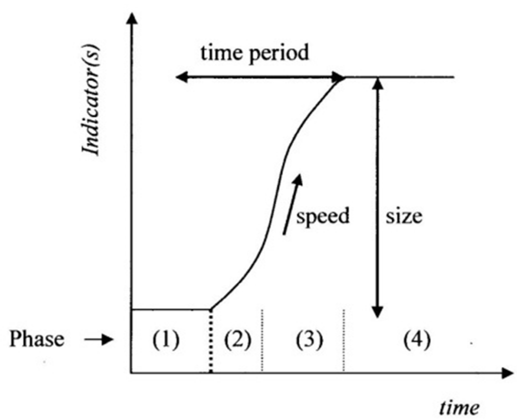

Figure 2. *Transition phases and indicators [4].*

Given an indicator or a set of indicators for transition, three system dimensions may be identified as shown in figure 2; the *time period* of a transition, the *speed* and the *size of the change* [15]. The four phases indicate that transitions follow a definite pathway and therefore, designing this pathway is equivalent designing a transition which requires unambiguous measurable performance indicators [8]. This necessary because the pathways are directly linked to indicators as shown on the vertical axis.

3. Socio-technical Transition Pathways

Transitions do not occur without a reason; they come about in response to negative external developments at the landscape level, caused by activities at regime level, resulting to an imbalance in the system [2]. This landscape-regime disagreement is subsequently resolved by regime changes through diffusion of elements from the niche level as catalyst or instruments of change [1]. These three levels form the multi-level perspective (MLP) framework of transitions and the different interactions among these levels lead to transition through different routes [16]. For instance, a transition can be a function of regime only dynamics or may involve the landscape level or both landscape and niche levels. The different routes or scenarios through which a transition can be achieved are known as the transition pathways. These pathways are discussed below.

P0 Reproduction pathway: This pathway is a result of regime reproducing itself in the absence of landscape pressure and without the introduction of new innovations into regime; hence it is a regime only transition [17]. The absence of landscape level means there is no pressure on regime actors to change orientation and/or adopt new innovations. However, the regime is dynamically stable in the sense that dynamics such as market competition, new investments etc. have been in existing. The aim is only to optimize; system improvement or system optimisation, without tempering the basic regime settings. Regime players often have the impression that minor problems that may arise within the regime could be resolved using internal solutions without the need of any external input. According to Rosenberg (cited in [3]), achievements in reproduction are a result of invisibly slow accumulation of modifications through small and continuous innovation improvements.

P1 Transformation pathway: Transformation pathway occurs as a result of the perceived need for regime re-orientation arising from moderate landscape pressure at a time when niche innovations are not sufficiently developed for market adoption. These pressures are usually translated by societal pressure groups and social movements. Since landscape pressure is not sudden, the need for better and viable alternatives causes regime insiders to change orientation through modification of existing regime components (maintaining incumbent regime technologies). In transformation pathway, regime actors survive as new regimes evolve from old regimes through cumulative adjustments and gradual trajectory realignments; new innovations used as add-ons while radical innovations remain restricted to niches, leaving the basic regime architecture unchanged [18].

P2 Substitution pathway: When a regime is destabilized under enormous landscape pressure at a time when a niche technology is fully developed, windows of opportunity for the new technology is created, allowing it to compete favourably with the incumbent dominant technology, ultimately replacing it [19]. Thus, it is a result of interplay between all the three levels on the MLP. The dynamics in substitution is that landscape pressure comes into effect at a time when niche innovations are sufficiently developed but remain stuck, owing to the insensitivity of regime actors to invest in them. Reasons behind reluctant actor attitude could be a result of the inertia created by existing regime practices. Subsequently, new markets for the innovations emerge leading to competition between new and old investors. Through a technology push mechanism, an eventual replacement of incumbent technology by a new one gives rise to an architectural regime change [20].

P3 De-alignment/Re-alignment pathway: This pathway occurs under the influence of a sudden and huge landscape pressure on a regime, causing the destabilisation and subsequent erosion or de-alignment of a regime. When this occurs at a time when none of the niche-innovations is sufficiently developed, there will be no clear substitute for the eroded regime [3]. This leads to uncertainties in choice and adoption, causing the exploration of different possible trajectories and the emergence of numerous niche-innovations in the vacuum created, resulting in a prolonged competition for a leading position. After a long period of co-existence, competition and learning, a niche-innovation emerges as a dominant technology, forming the centre for re-alignment and re-institutionalisation of a new sociotechnical regime. Thus, de-alignment/re-alignment pathway involves interactions between all three levels on the MLP [21]. This pathway results to a major restructuring of the system in terms of new guiding principles, beliefs and practices [22].

P4 Reconfiguration: This pathway occurs when a system changes through cumulative component changes and new combinations through the adoption of niche-innovations [19]. The alignments of alternative interlocking technologies result in new regime architecture and broader changes in the system. The niche innovations were initially adopted in the regime as supplementary components to improve performance and optimize productivity. At this point these alterations were not enough to trigger changes in regime rules and the basic architecture normally remains unchanged (a transformation pathway) [3]. Overtime, learning processes may reveal potential roles of novelties in the regime, opening up windows of opportunity for niche-innovations. Subsequent innovations further lead to social and technical changes and under continued landscape pressure, gives rise to large-scale re-alignment and re-orientation of the socio-technical regime. The reconfiguration pathway can best be described under the context of a distributed socio-technical system with multiple interrelated technologies such as agriculture, hospital, etc. [21].

4. Analysis and Discussion

The previous sections looked into literature concerning transition pathways resulting from multi-level interactions. The question will be what are the similarities and differences among the pathways? What is the possible sequence(s) in these pathways if a transition should cover all the pathways? The roadmap to the pathway analysis will follow the direction of landscape pressure increase and cost-performance improvements of niche technologies (in respect to regime technologies). This is because the driving force in regime transitions is strongly dependent on changes in the two MLP boundary levels; the landscape and niche.

4.1. Transition Characteristics of the Pathways

The transformation pathway T has the quality of absorbing and personalizing niche technologies (NTs) while the regime basically (architecturally) remains unchanged, thus the interaction of niche-regime technologies during transitions and the co-existence of new/old regime technologies (RTs) after transitions. A transition that goes beyond the transformation pathway (in landscape pressure and/or niche maturity levels) begins to substantially engage NTs into the regime. The reconfiguration R has the quality of absorbing, personalizing and eventually releasing (ejecting) NTs in the regime, while changing the basic architecture. Similar to T, R is also characterised by the interaction of niche-regime technologies during transitions and the co-existence of new/old RTs after transitions. In the substitution S, an NT emerges and pushes a dominant RT, eventually replacing it and making it a minor, thus a short period of niche-regime interaction at the beginning followed by a proper interaction and co-existence of new/old RTs during and after transitions. The de-alignment/re-alignment pathway (D/R) does not have interaction/co-existence characteristics of niche-regime or new/old regimes during and after transitions because existing regimes instantly give way to alternative niches just as transition begins owing to the highly disruptive nature of the landscape pressure. A dominant technology emerges from alternative and competing niches in the absence of old dominant RTs.

A close observation of the pathways reveals that T and S are similar in that both have remains of old technologies after transition. Similarly, R and D/R are also similar because both have the characteristics of eliminating old technologies after transition, giving rise to an entirely new regime. In the same vain, T and R are similar in that both have the characteristics of absorbing niche contents in response to landscape developments, although dynamisms in R are advanced stage of T. Moreover, both T and R do not involve a single emergent dominant technology in the transition process but rather multiple inter-locking technologies in distributed areas intended for a common goal. Similarly, D/R and S exhibit similarities in that transition in both cases are centred on the emergence of a single dominant technology in regime throughout the transition process. In addition, R and S also exhibit similarities because in both cases, an old technology is being displaced and replaced by new ones, although R involves multiple technology emergences and S involves a single technology emergence. However, each pathway has a unique feature that may not be comparable to any of the other pathways.

The similarities among the pathways give rise to a web-like diagram which may be represented as shown in Figure 3. The difference between D/R and S is that potential dominant RTs in D/R face emergence competition from alternatives at niche levels and attain a freedom of growth at regime levels resulting from the absence of incumbent regime competitors whereas in S, the reverse is the case; a competition from an incumbent regime during growth and a freedom of emergence from the absence of niche counterparts at niche level. In other words, D/R has an initial transition resistance (during pre-development and take-off phases) and a later transition freedom (during acceleration phase), whereas S has an initial transition freedom and a later resistance.

Table 1. *Relative characteristics of transition pathways [3].*

Pathway		Transformation	Reconfiguration	Substitution	De-alignment/ Re-alignment
Landscape pressure P_L		moderate/spread	high/spread	very high/ concentrated	unbearable/ concentrated
Maturity of niche technology at P_L inception		low	moderate	full	moderate
Niche-regime co-existence during transition		present	present	present	absent
Transition mechanism		niche absorption	niche absorption/ ejection	technology push/ displacement	technology disappearance/ appearance
Phase speed/time	Pre-development	slow/long	very slow/very long	fast/short	fast/very long
	Take-off	fast/long	slow/long	fast/short	slow/long
	Acceleration	fast/long	slow/long	fast/short	slow/long
	Stabilisation	slow/long	slow/ very long	slow/short	slow/long
Degree of change		modular	architectural	architectural	architectural
Changes involved		incremental-modular	modular-radical-architectural	radical- architectural	architectural
Regime revolution	Incumbent actors' fate after transition	majority	majority/ minority/ extinction	minority	extinction
	Institutions/ rules changes	moderate	high	very high	new
	Technical variations	moderate	very high	very high	new

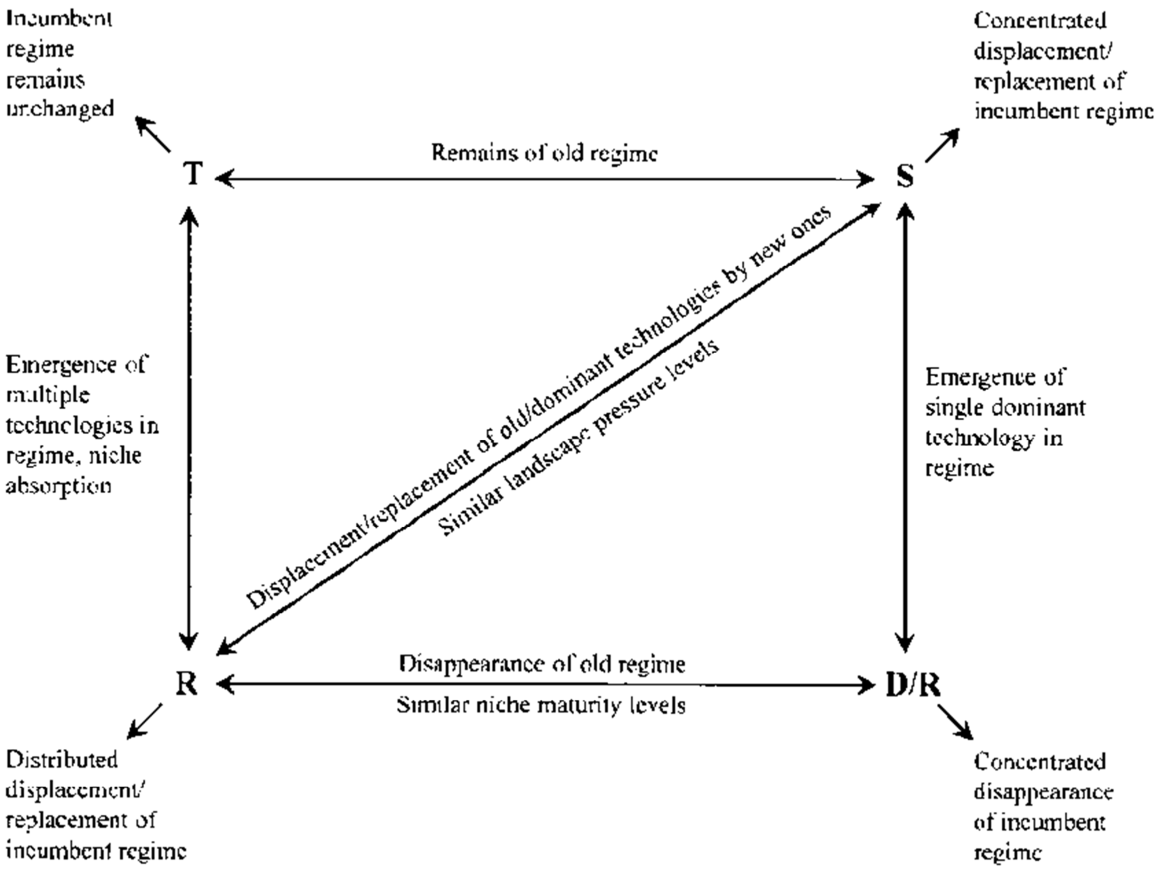

Figure 3. *Similarity diagram for the transition pathways [3].*

The advantage of fast/short acceleration phase in D/R as a result of low transition resistance arising from incumbent regime disappearance is attributed to the "unbearable landscape pressure" which precedes niche competitions for dominance, whereas the disadvantage of prolonged pre-development and take-off phases (niche competition) resulting from high transition resistance at niche level is a result of the lack of a fully matured niche technology that can guide a timely investment direction. On the other hand, the fast/short pre-development and take-off advantage in S due to low resistance at niche level is a result of the existence of a fully matured NT free of competition, which precedes landscape pressure, whereas the relatively slow acceleration disadvantage due to high resistance is a result of entrenched regime incumbents during NT growth. It may be said that D/R is equivalent to S plus niche competition minus regime competition or S is equivalent to D/R minus niche competition plus regime competition. Table 1 above summarises the relative characteristics of the transition pathways.

4.2. Graphical Illustration of the Transition Pathways

Transitions are usually initiated by the impact of disruptive landscape pressures on regime [2]. The development of this pressure reaches a point where the regime can no longer bear its normal activities and begins response to the landscape. Niche level contents are adopted by the regime under the continued action of the landscape to solve perceived problems. The transition (and usually also the landscape pressure) ends when the social and technical components of the new socio-technical regime stabilise together. We therefore distinguish two phases of landscape pressure development; the first phase with a static effect on transition, occurring before transition starts (the static landscape pressure) and the second phase with a dynamic effect on transition, occurring during the transition process (the dynamic landscape pressure). The maximum point of the static landscape pressure (P_{Ls}) or the minimum point of the dynamic landscape pressure (P_{Ld}) marks the starting point of transitions. The landscape pressure that marks the beginning of transitions may also be referred to as the transition landscape pressure (P_{Lt}).

As illustrated on Figure 4, the vertical axis on the left represents landscape pressure development P_L, the horizontal axis represents niche development factors in terms of the performance-cost ratios which is a function of time $\gamma_n(t)$, and the vertical axis on the right is for regime changes, i.e. transition τ. Regime change starts from incremental, through modular and radical, and finally ends with architectural change. Also, the dashed and solid lines represent the static pressure (P_{Ls}) and the dynamic pressure (P_{Ld}) respectively. The magnitude and intensity (with respect to time) of these pressures is represented by the height (P_L) and slope (P_L/γ_n) of the pathways respectively. The values for the magnitude and intensity (for both static and dynamic landscape pressure) differ among the various pathways. In addition, the starting point of each pathway relates the maximum P_{Ls} or the transition pressure P_{Lt} to a value of γ_n in accordance with the literature. Since transitions start at P_{Lt}, assuming a linear relationship between technology development γ_n and time *t*, then the various pathways and their phases will be as shown in Figure 4 below.

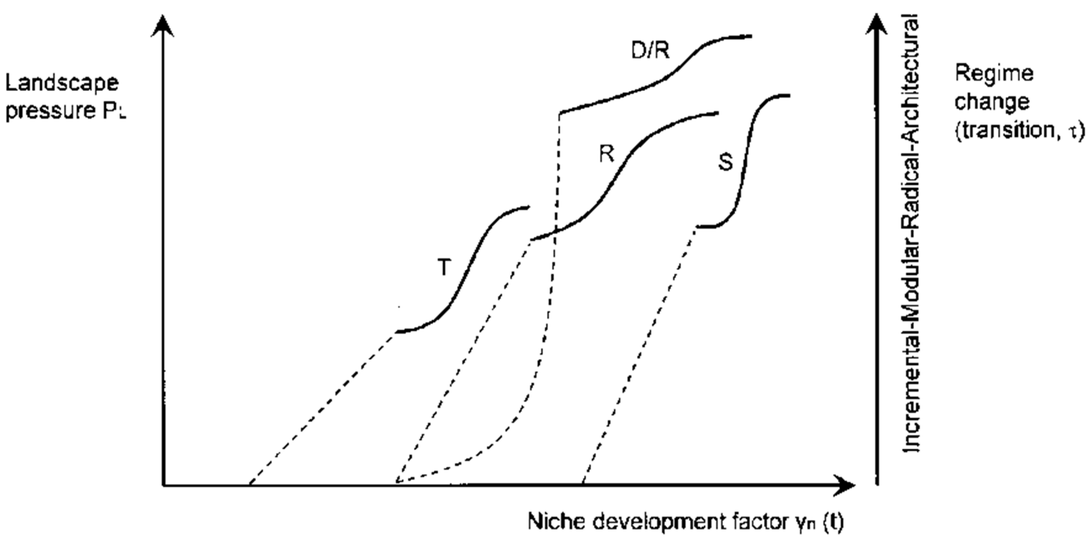

Figure 4. *Graphical illustrations of transition pathways [3].*

As shown on the graph, the transformation pathway T is characterised by moderate and gentle landscape pressures P_L (both static and dynamic) on regime and starting at a time (t) when the niche technology (NT) development factor γ_n is low. The pressures for T starting at an early value of γ_n, are also gentle as the slope P_L/γ_n is low, while the transition pressure P_{Lt} is moderate. All the phases involved in this pathway extend considerably over a period (t) of niche innovation process. This is because the multiple niche contents only develop (and are subsequently absorbed by regime) over time

($\gamma_n(t)$). Because both P_{Lt} and γ_n are relatively low, transitions in T end with a modular change (τ axis), leaving the basic architecture of the regime unchanged. A similar pattern may be observed from the reconfiguration pathway R which also extends over a considerable niche development period, although starting at a later stage of γ_n factor with a higher P_{Lt}. It also extends over a wider and higher maturity phase of NT development period compared to T. Both the static and dynamic pressures (P_{Ls} and P_{Ld}) for R are higher and also steeper than in T, making transitions in R an architectural change.

For the de-alignment/re-alignment pathway D/R, the static pressure P_{Ls} starts at a moderate value of γ_n and grows gradually in the beginning and suddenly escalating to a very high value within a short time, attaining P_{Lt} (at similar γ_n to R) with a highly disruptive effect on regime. Transition is triggered, the regime crumbles and the prolonged pre-development and take-off phases in D/R cover a long range of $\gamma_n(t)$ axis as indicated. Although dynamic pressures in D/R are not too high, the transitions end with architectural changes because of the enormous effect of P_{Lt} which erodes the regime, giving way to entirely new one. Finally, the static pressure P_{Ls} in S starting at a high value of γ_n grows rapidly to its peak at P_{Lt} to trigger a transition. The dynamic pressure period (or transition period) for this pathway is relatively short because NTs are already fully developed. Thus the pathway S does not extend over a long range of γ_n and transition processes are relatively fast, driving the regime change to an architectural change.

4.3. Limitations of the Graph

1) The assumption that niche technology development is linear with time might not always be true, especially when there is a technology breakthrough.
2) The starting points of the pathways in relation to the transition axis (τ axis) give the impression that the pathways start at a time when regime change has occurred, and thus should be neglected.
3) The changing slopes and the stabilisation phase pressures of the pathways (with respect to t-axis) do not give accurate relationships with the P_L axis and thus should only relate to the τ axis.

4.4. Possible Pathway Sequence

Transitions may involve one or more of their pathways which may be occurring at different or same times. For a transition that is distributed in more than one societal sector level (a multi-sector level transition), it is possible to have different sectors undergoing same or different pathways at a given time. It is even possible to have a coincidence of starting points of pathways among the different sectors. The concurrent pathways among the different sector levels are likely to be the same where the percent sector contributions in landscape development do not differ significantly, otherwise they are likely to be different. In this case, there is less interdependence of the existence and interactions of pathways among the various sector levels. However, this might not be the case when the transition is viewed from a single level or with transitions that involve only one sector level, because pathway emergence in this case are more interdependent. Therefore, where all the pathways are involved, uni-sector level transitions better reveal the possible sequence of pathway emergence whereas multi-sector level transitions have a higher tendency to combine more pathways and are more independent because of the broader transition scene.

Although transitions in both the cases may not have to involve all the four pathways and exhibit some pathway independence, a possible sequence may be defined in terms of the values of P_L and γ_n such that the occurrence of a particular pathway for a transition becomes a measure of the seriousness of a situation and progress in the desired direction. This implies that a higher scenario in the sequence means a further and closer step to the object of transition in a more serious situation than a lower scenario. Based on [3], progressive landscape development first attains the transition pressure (P_{Lt}) level of the transformation (T), through the reconfiguration (R) and substitution (S) and finally de-alignment/re-alignment (D/R), i.e.;

$$P_{Lt.T} < P_{Lt.R} < P_{Lt.S} < P_{Lt.D/R}$$

For the corresponding NT development factor γ_n, the sequence begins with T, through R or D/R, and finally S, i.e.;

$$\gamma_{n.T} < \gamma_{n.R} / \gamma_{n.D/R} < \gamma_{n.S}$$

Except for S with $\gamma_n \geq 1.0$, the starting niche development levels for all the other pathways are such that $\gamma_n < 1.0$.

It is clear that R is next to T both in P_{Lt} and γ_n levels but what is not clear is the next superior scenario to R. S is closer to R in the P_{Lt} direction whereas D/R is closer to R in the $\gamma_n(t)$ direction. Therefore, the sequential pathway ranking in the direction of landscape pressure will be in the sequence T-R-S-D/R, whereas in the direction of niche maturity levels, the sequence will be T-R-D/R-S. The next stage will be to compare the P_{Lt} gap of D/R to R ($P_{Lt.D/R} - P_{Lt.R}$) and the γ_n gap of S to R ($\gamma_{n.S} - \gamma_{n.R}$) as well as the rates of change of P_L and γ_n. This is because a developing phenomenon involving a fast speed or a short distance precedes one with a slow speed or a long distance. In transitions therefore (assuming equivalent differences for $P_{Lt.D/R} - P_{Lt.R}$ and $\gamma_{n.S} - \gamma_{n.R}$), when niche development is relatively faster than landscape development from R, the pathway sequence T-R-S-D/R becomes more likely whereas a faster landscape development than niche favours the sequence T-R-D/R-S. In the same vain (assuming equivalent rates of change of P_L and γ_n), when the $P_{Lt.D/R} - P_{Lt.R}$ difference is wider than $\gamma_{n.S} - \gamma_{n.R}$, T-R-S-D/R is more likely and when $P_{Lt.D/R} - P_{Lt.R}$ difference is shorter than $\gamma_{n.S} - \gamma_{n.R}$, T-R-D/R-S is more likely. Therefore, in the case of equivalent P_{Lt} differences and P_L and γ_n change rates, then beyond *a*, an intermediate scenario *X* for D/R and S may be observed (Figure 5).

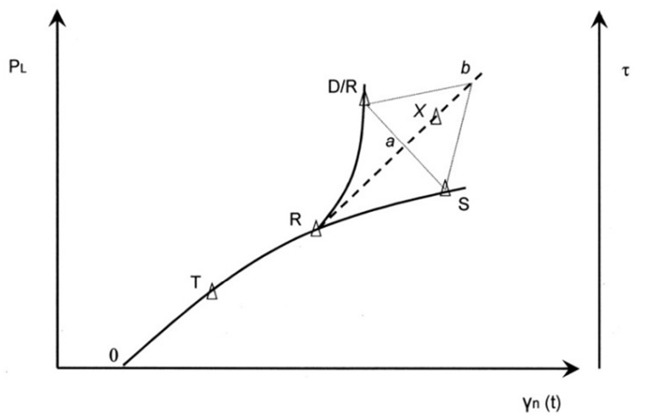

Figure 5. Alternate sequence of the transition pathways.

The minimum value for X will be at a while the maximum value will be at b where $P_{Lt.D/R}$ and $\gamma_{n.S}$ have been attained. Triangles R-D/R-S and b-D/R-S will be isosceles and the slope P_L/γ_n at any point along line R – b is constant. In this scenario, part characteristics for both D/R and S begin to emerge. The resultant effect of X on a regime may be an incomplete de-alignment of an incumbent dominant technology resulting from the high P_{Lt} alongside the emergence of near-fully developed alternative(s). If only one single NT attains the development level in X, resistance in emerging as dominant will be lower than S because of the partial space created by the shrinking dominant regime due to P_{Lt} enormity. If multiple NTs attain the development level in X, the result will be the emergence of near-fully developed niche alternatives. In the race for the dominant position, the emergence resistance will still be lower and less intense than in D/R because of the high confidence and low uncertainty in investment among all the alternatives. The dominant position is instantly occupied giving rise to a dominant regime practice alongside other strong alternatives.

Again two conditions might be identified; whether the strong alternatives have become part of the regime or are confined to the niche level owing to the high acceptability of the dominant practice. In the former case, the regime will be more or less stable because of the already defined regime settings. In the later case however, in view of the availability of strong niche elements, there is every tendency that the new dominant regime might not maintain this position for a long time that another niche replaces it. Eventually, we will have an unstable substitution pathway with a partly de-aligned regime involving what looks like competing niches. Therefore in addition to the magnitude of external development and the niche maturity level, determinants in scenario X also include the number of emerging niches with the upsurge of landscape development.

Consequently, X involves both S and D/R characteristics in that substitution is involved although unstable, and a high disruptive pressure and de-alignment is also involved although partial, in association with competing technologies although at different niche/regime levels. Furthermore, it is not S because the incomplete downfall of incumbent regime is not attributable to ‘technology push’ (absence of its transition mechanism) and also the instability of new regimes in view of the seemingly competing technologies, neither is it a D/R because of the inadequate disruptive pressure, incomplete disappearance of incumbent regimes, and a relatively fast emergence of a dominant option. Finally at b, complete regime de-alignment and full NT maturity levels are expected which further eases the transition process in terms of low investment uncertainties and absence of an entrenched regime.

However, due to possible deviations from these assumptions in theory, triangles R-D/R-S and b-D/R-S might not be isosceles and between R and b, the slope P_L/γ_n will not be constant (it will deviate from line R – b). This implies that X could be located anywhere within the region b-D/R-S, but the location of X (determined by the coordinates of P_L and $\gamma_n(t)$) and the rate of change of P_L with respect to γ_n (determined by the slope $\delta P_L/\delta\gamma_n$ at X) determine the status of the scenario in terms of D/R and S. In general, scenario X is more of D/R if its location is in the region b-D/R-a or is D/R biased when the slope $\delta P_L/\delta\gamma_n$ at X is greater than that for R – b and is more of S if its location is in the region b-S-a or is S biased when the slope $\delta P_L/\delta\gamma_n$ at X is less than that for R – b.

4.5. Effect of Pathway History on P_L Development and Sequence

The rate of change of P_L in turn depends on the pathway history of a transition. For a specific transition, the occurrence of a transition pathway tends to decrease or eliminate the negative consequence of landscape developments, thereby prolonging growth time of landscape pressures and extending the need for another transition (and hence pathway). Therefore, a transition that witnessed more pathways before D/R and S would have a lower P_L change rate or time intensity than one that has not and the slope $P_L/\gamma_n(t)$ beyond R decreases in favour of T-R-S-D/R.

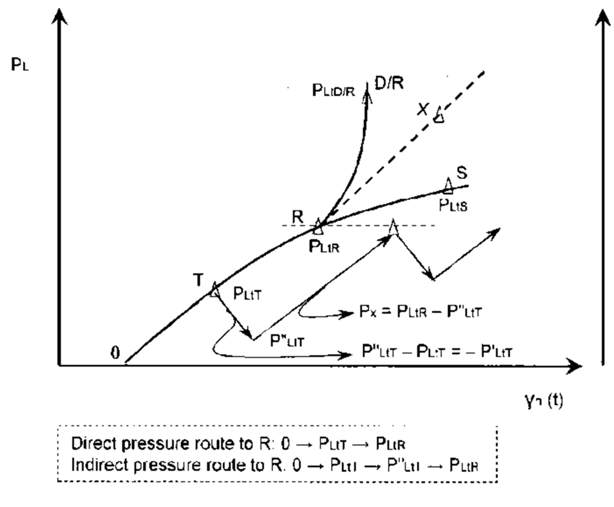

Figure 6. Effect of transition pathway history on P_L intensity.

Consider a landscape development that rises to $P_{Lt.T}$ to cause transformation pathway (T). As shown in figure 6, the action of T decreases this pressure by – $P'_{L.T}$ to a lower value of $P''_{L.T}$ (such that $0 \leq P''_{L.T} < P_{Lt.T}$) and therefore the leftover landscape pressure at T, would be;

$$P''_{L.T}=P_{Lt.T} - P'_{L.T} \quad (1)$$

This means that $P_{Lt.T}$ has been cut down to $P''_{L.T}$ by T which needs additional landscape pressure development (and hence time) say P_{Lx} to rise to $P_{Lt.R}$, i.e. $P''_{L.T} + P_{Lx}=P_{Lt.R}$ and hence;

$$P''_{L.T}=P_{Lt.R} - P_{Lx} \quad (2)$$

Solving for P_{Lx} by equating equations (1) & (2) gives;

$$P_{Lx}=|P'_{L.T}| + (P_{Lt.R} - P_{Lt.T}) \quad (3)$$

(which implies that $P_{Lx} > P_{Lt.R} - P_{Lt.T}$).

Let the corresponding times required by $P_{Lt.T}$, $P'_{L.T}$, $P''_{L.T}$, P_{Lx} and $P_{Lt.R}$ be t_{T1}, t_{T2}, t_{T3}, t_x and t_R respectively. Then the indirect route of pressures to R through T will be $0 \rightarrow P_{Lt.T} \rightarrow P''_{L.T} \rightarrow P_{Lt.R}$ while the summation of the corresponding pressure changes involved will be;

$$P_{Lsum.ind}=P_{Ls.T} - P'_{L.T} + P_{Lx} \quad (4)$$

And the summation of the corresponding times is;

$$t_{sum.ind}=t_{T1}+ t_{T2}+ t_x \quad (5)$$

The direct pressure route to R, is $0 \rightarrow P_{Lt.T} \rightarrow P_{Lt.R}$ while the corresponding pressure change summation is $P_{Ls.T} + (P_{Ls.R} - P_{Ls.T})=P_{Ls.R}$, therefore;

$$P_{Lsum.dir}=P_{Ls.R} \quad (6)$$

And its corresponding time is;

$$t_{sum.dir}=t_R \quad (7)$$

By substituting eq. (3) into (4), the indirect route pressure sum will be;

$P_{Lsum.ind}=P_{Ls.T} - P'_{L.T} + P_{Lx}=P_{Ls.T} - P'_{L.T} + [P'_{L.T} + (P_{Ls.R} - P_{Ls.T})]=P_{Ls.R}$, (recall eq. 6) then;

$$P_{Lsum.dir}=P_{Lsum.ind} \quad (8)$$

Since $P_{Lt.R}=P_{Lt.T} + (P_{Lt.R} - P_{Lt.T})$ and $P_{Lx} > P_{Lt.R} - P_{Lt.T}$, then $|P_{Lt.R}| < |P_{Lt.T}| + |P'_{L.T}| + |P_{Lx}|$ and hence for $P_{Lt.R}$ development through the different routes, $t_R < t_{T1}+ t_{T2}+ t_x$, (recall eq. 7 & 5) then;

$$t_{sum.dir} < t_{sum.ind} \quad (9)$$

Although in both cases of the direct and indirect routes to R, the final common pressure is $P_{Lt.R}$ (eq. (8)), the respective time periods t_R and $t_{T1}+ t_{T2}+ t_x$ are such that $t_R < t_{T1}+ t_{T2}+ t_x$. Therefore, the time intensity of $P_{Lt.R}$ through the two routes will differ:

For the direct route (without T action), the intensity will be $P_{Lsum.dir}/ t_{sum.dir}$, i.e.;

$$P_{Lt.R}/t_R \quad (10)$$

Whereas for the indirect route (with T), the intensity will be $P_{Lsum.ind}/t_{sum.ind}$;

$$P_{Lt.R}/t_{T1}+ t_{T2}+ t_x \quad (11)$$

The fact that $t_R < t_{T1}+ t_{T2}+ t_x$ indicates that $P_{Lt.R}$ is spread over a longer time period with the action of T and obviously the pressure intensities will differ such that;

$$P_{Lt.R}/(t_{T1}+ t_{T2}+ t_x) < P_{Lt.R}/t_R \quad (12)$$

Equation (12) means that the intensity of $P_{Lt.R}$ is reduced with the action of T; a previous pathway to R.

A similar observation can be deduced from the action of R on a next pathway. This means that in a transition, the rate of change of landscape pressure or the time intensity of P_L, i.e. P_L/t decreases with the actions of preceding pathways (along the sequence) due to increase in P_L growth period. And since niche maturity level γ_n is more or less linear with time, $P_L/\gamma_n(t)$ also decreases for the same reason. Generally, a transition that involves more of T and/or R at the early right stage of its landscape development is more inclined towards -S-D/R sequence than one that has not.

4.6. Effect of Transition Policy on γ_n Development and Sequence

Normative niche innovations and system improvements under reproduction pathways are accelerated by pressures from landscape and regime levels, just as promotions of incumbent regime technologies are challenged (and eventually decelerated) by landscape pressures. Under a disruptive landscape pressure, policy settings on specific regime practices affect the continuity and scale of their adoption. Stricter regulations and taxes on regime technologies (RTs) for instance have negative effect on their overall cost-performance factors γ_r, whereas dedicated research, development and deployment efforts and learning processes through funding, incentives and subsidies on niche technologies (NTs) improve their overall cost-performance factor γ_n (Figure 7). Overtime time therefore, infrastructure innovation and investment gradually shift towards NT development, leading to a competition between NTs and RTs. This implies that the relative performance-cost ratio of NTs in relation to RTs, γ_n/γ_r which is a function of time t, $(\gamma_n/\gamma_r (t))$ in a transition economy grows overtime (Figure 7).

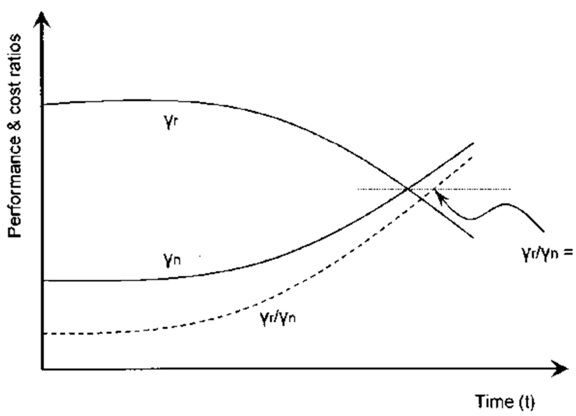

Figure 7. Effect of transition policy on γ_n development and adoption.

5. Conclusion

An additional depth of literature based analysis of transition pathways has been established to further enhance understanding of their characteristic distinctions and sequential linkages. Going by the direction of increase in landscape pressure P_L, transitions start with the transformation pathway (T), through the reconfiguration (R) and substitution (S), and finally de-alignment/re-alignment pathway (D/R), i.e. T-R-S-D/R. Going by maturity level of niche technologies (NTs) γ_n, the sequence will be T, through R or D/R and finally S, i.e. T-R-D/R-S. The P_L axis separates R & D/R at about the same γ_n levels whereas the $\gamma_n(t)$ axis separates R & S at about the same P_L levels. It has been noted that whether D/R or S succeeds R depends on the differences of $P_{Lt.D/R} - P_{Lt.R}$ and $\gamma_{n.S} - \gamma_{n.R}$ and the rates of change of P_L and γ_n. An increase in $P_L/\gamma_n(t)$ or a smaller $P_{Lt.D/R} - P_{Lt.R}$ than $\gamma_{n.S} - \gamma_{n.R}$ favours the sequence T-R-D/R-S whereas a decrease in $P_L/\gamma_n(t)$ or a larger $P_{Lt.D/R} - P_{Lt.R}$ than $\gamma_{n.S} - \gamma_{n.R}$ favours the sequence T-R-S-D/R. In the case of equivalent change rates of P_L and $\gamma_n(t)$ from R, and where the $P_{Lt.D/R} - P_{Lt.R}$ and $\gamma_{n.S} - \gamma_{n.R}$ differences are not too different, a fifth scenario (*X*) which combines part characteristics of both D/R and S has been observed. Where this assumption does not hold, *X* is unstable and the measure of D/R and S features therein depends on its location in triangle *b*-D/R-S. Another determinant of *X* feature with respect to D/R and S is the instantaneous rate of change $\delta P_L/\delta\gamma_n(t)$. *X* is D/R biased when the slope $\delta P_L/\delta\gamma_n(t)$ increases and is S biased when $\delta P_L/\delta\gamma_n(t)$ decreases. An additional factor determining *X* feature is the number of emerging alternative technologies associated with it.

Also, another determinant of the pathway sequence lies in the pathway history of a transition. A transition that has involved more of the first two pathways (T and R) is likely to acknowledge S as the next scenario to R because in this transition, P_L is not fully cumulative due to the actions of T and R which reduce the growth rate P_L/t of landscape pressure. Subsequently, a slow P_L may affect a timely attainment of $P_{Lt.D/R}$ required to trigger D/R, therefore T-R-S-D/R is likely. In all case however, it is necessary to establish precise measurements for P_L and γ_n for all the pathways including their rates of change to give a precise conclusion on a clear status of the pathways and the sequence especially in terms of D/R and S positions. Also formulation of numerical values of and relationships between landscape pressure P_L, niche maturity γ_n and regime change (transition τ) for the pathways is important for a clear understanding of their dynamics and sequence. Adequate knowledge on pathway dynamics and sequence help to easily identify a likely scenario when a disruptive landscape pressure is imminent and subsequently, its suitability and performance in terms the goals of transition. Such insights help in guiding socio-technical transitions in the most efficient way by designing relevant and timely precautionary measures.

Acknowledgements

This research was supported by the University of Maiduguri, Nigeria. We thank our colleagues who provided insight and expertise that greatly assisted the conduct of the research. We thank the Dean Faculty of Engineering, and the H. O. D. Civil Engineering Department, for their assistance and comments that greatly improved the quality of the manuscript.

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