Assessing the Effects of Sustainability Practices on Product Life Cycle- Clustering Approach

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Abstract
Enterprises are under surveillance for their product's environmental footprints, quality dimensions and production system environment. In addition, there is a growing concern of liability for entire product life cycle where firm is responsible for consequences caused by product till its useful life. Enterprises are urged to adopt a Triple Bottom Line approach of sustainability to respond effectively to the dynamics of Profit, People and Planet. We use *LISREL* based Structural Equation modeling to identify the mediating role of product life cycle in the relationship of sustainable practices and firm performance. Based on the findings, Exploratory Factor Analysis is performed to identify cluster of sustainable practices for each product life cycle. The recommended framework can be used by practitioners as a decision support tool in exercising sustainable practices in each product life cycle stage.

Keywords
Product Life Cycle, Sustainability, Mediating, Triple Bottom Line.

1. Introduction
Organizations in today's business context are faced with multiple challenges. Some of the challenges are internal to the business environment while some are external (Leonidou *et al*., 2017). The challenges within organization are related to productivity, quality improvement, workmanship and employees' training. As employees are important part of the business, they need to be trained and empowered (Schwartz, 2017; Clarke, 2018). Similarly, external pressures are from customers and government. Government legislation enforces liability on employees, customers and environment. Considering the role of employees, customers and government, a Triple Bottom Line *(TBL/3BL)* approach is suggested for an environment friendly production, customer driven policy and an employee friendly workplace (Ozgun *et al*., 2015). Moreover, there is a need to initiate sustainability protocols to pay more attention to the negative environmental consequences of product in different life cycle stages (Charter *et al*., 2017). This study has two objectives. First, role of adopting sustainable practices according to product life cycle stages is highlighted. Structural Equation Modeling is used to quantitatively investigate the mediating effect of Product Life Cycle *(PLC)* stages in the relationship between Sustainable Practices *(SP)* and Firm Short Term *(STP)* and Long-Term Performance *(LTP)*. Based on the findings, clustering of *SP* bundles according to different *PLC* stages is performed using Exploratory Factor Analysis *(EFA)*. Life cycle stages considered for this study are introduction, growth, maturity and decline (Anderson *et al*., 1984).
Products throughout their life cycle pass through different stages by varying in terms of profit generation, meeting social needs, and environmental footprints. Since *PLC* encompasses all stages of a product, from inception till deception, life cycle analysis *(LCA)* measures the impact of the product's performance starting from raw material, production, repair till the end of life, and recycling. Modern life cycle analysis evolved in 1990s (Dubey *et al*., 2017) and is regulated by ISO 14040 and 14044. Product evolution is a complex phenomenon for an enterprise to apply *LCA* approach due to societal dynamics, environmental uncertainties and imperfections within the business (da Luz *et al*., 2018). In production contexts, *LCA* has passed through Cradle-to-Grave, Cradle-to-Cradle and Design for Manufacturing (DFM). More focus is on End-of-Life *(EOL)* practices where maximum values are extracted after useful life of a product to minimize its negative footprints (Hourneaux *et al*., 2018). There is a need to adopt *PLC* stages based sustainable practices to enhance corporate social responsibility.
It is recognized that an enterprise plays a key role in implementing sustainable practices for attaining strategic edge (Hamann *et al*., 2017). Sustainable practices are receiving research attention for the last two decades, especially in the context of corporate social responsibility (Marshall *et al*., 2015). Customer perception drives the social responsibility index and enterprises are urged to limit their environmental consequences for a sustainable society (Dzikuć, 2015). *Sustainability is defined as the creation of products that use processes to minimize negative environmental footprints, reduce energy consumption, are safe for workers, societies, costumer and economically*

justifiable (Leiserowitz, 2005; Chawla *et al*., 2018). Our understanding of sustainability has changed from a static and generalized characteristic of a system to the dynamic characteristics of system (Morellet *et al*., 2009) which make sustainability a "moving target" (Gaziulusoy *et al*., 2008). Enterprises are diverting their interests more towards the introduction and growth stages. Introduction stage is important from an enterprise viewpoint as there are "W" questions regarding the competency of their products and acceptability by customers (Anderson *et al*., 1984; Stark, 2015). Similarly, growth is the profit generating *PLC* stage. Research shows that product loses the interest of an enterprise in the maturity and decline stages because of fewer profit margins as the product becomes obsolete (Wu *et al*., 2017). Practitioners either replace the product by a new version or stop the production of similar product family. In line with the Triple Bottom Line *(TBL)* approach, we argue that enterprises need to take equal responsibility of the product's maturity and decline phases as in such stages; product becomes more consequential for the environment due to deteriorating performance (Li *et al*., 2017). We emphasize that sustainable practices adoption in all stages of *PLC* (maturity and decline stages in particular) can result in good returns in short term as well as long term. For example, retrieving the declining products and recycling them can save up to 60% of the manufacturing cost for an enterprise (Ginsburg, 2001). It also helps in reduction of waste and low carbon economy. Also, remanufacturing is a good business strategy for the conservation of energy in mobile phones and computers industry (Quariguasi *et al*., 2012). The aim of this research is to build foundations on the dynamic behavior of sustainability and its interaction with product life cycle stages considering *RBV* (De Gouvea, 2001). A research framework is proposed to assess the following questions statistically:

1. *What is the effect of sustainable practices adoption on firm's short term and long-term performance?*
2. *What is the mediating role of product life cycle between sustainable practices and firm's performance?*
3. *What are the bundles of sustainable practices relevant to each product life cycle stage?*

First part of the study addresses the first two (2) questions and on the basis of findings, *EFA* analysis is performed to identify relevant sustainable practices for each *PLC* stage.

2. Literature Review

2.1. Product Life Cycle Management

The concept of *PLC* analysis was first applied in Europe in a bottle making industry to understand its negative footprints (Hunt *et al*., 1996) and has since received attention in sustainability and environmental footprint literature. *LCA* approach is used in multiple contexts such as production facilities, chemical products, manufacturing of goods and service industries (Smith, 1990; Wang *et al*., 2018). Continuous assessment is an essential feature not only to improve the quality of product but also to reduce waste of defects and disposing off. There are distinct product families and modular parts which are produced on the same assembly and manufacturing lines. From user perspective, a product becomes useless if its important component stops working. It is suggested to produce parts with same life expectancy (Kutz, 2007). Production and assessment of products is an on-going activity which involves life cycle analysis and adopting required sustainable practices. Managing each *PLC* stage can result in many advantages for an enterprise. For example, the growth stage can be prolonged resulting in more profit, environmental consequences can be reduced in the later *PLC* stages through constant monitoring, end-of-life products retrieval can help the enterprise to extract value from salvaged products and it can help in improving the Corporate Social Responsibility *(CSR)* indices by engaging with the customer for product feedback at each *PLC* stage.

2.2. Sustainable Practices and Triple Bottom Line

Sustainable products are defined as *"products which provide environmental, societal and economic benefits while protecting health, welfare and maintaining the environment throughout their life cycle"* (Go *et al*., 2015). Similarly, sustainability in a production environment is defined as the means for extracting value from developments to meet the needs of today without a compromise on the needs of future generations (Leiserowitz, 2005). Adoption of sustainable practices in the modern practices is an important parameter of social responsibility and it has gained attention from researchers as well as practitioners (Hakt *et al*., 2018). Manufacturing enterprises are urged to provide products to customers with an added value and sustainable features (Bevilacqua *et al*., 2016). Although, the concept of sustainable practices and environmentally friendly manufacturing is quite old (Carson, 1962), organizations are trying to comprehend the benefits they can obtain from implementing sustainability on policy level (Hassini *et al*., 2012). A debate is initiated by the practitioners on the implementation of *SP's* and their cohesion

with the organizational needs, production capabilities and efficiency (Wagner, 2014). Empirical findings suggest that implementing *SP* is rewarding both financially as well as environmentally (Høgevold *et al*., 2014).
Triple Bottom Line *(TBL)* approach was introduced in the late 1990's to prescribe essentials of economic, social and environmental needs of an organization (Hammer *et al*., 2017). The immediate outcome of implementing a *TBL* approach is economic values; however, organizations need to assess the impact of their products on social and environmental needs (Pagell *et al*., 2009). Triple Bottom Line approach integrates economic, environmental and social aspects of an organization to highlight the importance of 3Ps *(People, Planet and Profit)* (Norman *et al*., 2003). Literature suggests that organizations prioritizing the environment anticipate an increase in their financial returns by lowering the scrap rate, wastage and refusal (Borland *et al*., 2013) along with an improved management of the 3P's (Gmelin *et al*., 2018). *SPs* are considered key resources in providing an organization with rare, imitable and sustained competitive edge which is *RBV* perspective. Resources are strong pillars for enterprise effectiveness and application of *RBV* can help in the identification of competitive advantage enablers (Savino *et al*., 2015). An underlying tenet of *RBV* is that resources are to be tacit, rare and valuable so that they cannot be replicated in any other context (Coates *et al*., 2002). We posit that the adoption of sustainable practices in different *PLC* stages can provide sustained competitive advantages which are rare and valuable for an enterprise. In this study, measurement assessment of *SP* on firm performance is performed along with the mediating role of *PLC* stages between sustainable practices and performance indices & following hypotheses are tested.

H_1*: There is a significant relationship between sustainable practices and short-term firm performance*

H_2*: There is a significant relationship between sustainable practices and long-term firm performance*

H_3*: Product life cycle stages have a significant mediating role between sustainable practices and short-term firm performance*

H_4*: Product life cycle stages have a significant mediating role between sustainable practices and long-term firm performance*

3. Methodology

Survey research was adopted for analysis purpose and an adequate sample was drawn using convenient sampling technique. 5-point Likert scale-based questionnaire was administered to the respondents and the returned data was entered in *SPSS,* V_{22}. *AMOS* package was used for model testing and validation. The sample comprised of *200* respondents and sample was selected according to the position of the respondent in the enterprise, size and nature of the business. The second dimension of sample selection was based on the size of an enterprise and the number of employees associated with it. The respondent's sample was selected from a list of 25 enterprises including heavy production industries *(automotive, locomotive and construction),* large scale production *(bottle manufacturing and process industries)* and Small and Medium Enterprises *(SME's)*. Table1 contains the frequency and number of employees in the selected firms.

Table1 Size of Firms, Number of Employees and Representation in the Sample

Firm Size	Employees	No. of Firms
Heavy Production Industry	>500	8 (22.8%)
Large Scale Production	Between 100 & 500	10 (28.5%)
SME's	<100	17 (48.5%)

3.1. Measurement Scheme

Measurement scheme was devised for questionnaire administration by adopting scales of sustainable practices *(SP)* (Rusinko, 2005; 2007), firm short-term performance *(STP)* (Nybakk, 2012; Wu *et al*., 2015) and long-term performance *(LTP)* (Chin, 2010). Context specific scale was not available for *PLC* stages; hence, it was developed and validated by field experts. The distinction between short-term and long-term performance indices is the time to anticipate results. Short term performance results are more immediate in a time frame of 3-5 years while for long term performance results, time duration is considered between 7-10 years. Measurement scheme for this study is provided in Table2. The questionnaire was administered to the respondents online as well as by hand distribution. Total *200* questionnaires were distributed and *137* questionnaires were returned out of which *12* were void due to missing cases. *125* usable questionnaires were retained with a response rate of*62.5 %*. The internal consistency and reliability results were performed and the results are provided in Table3. The acceptable threshold value of item's factor loading is 0.707 (Hair *et al*., 2010). Except for three items of *PLC* construct, all of the items had a value greater than 0.707 (Hair *et al*., 2010). The deleted items were *synchronization between life cycle stages*, *profit margin between stages* and *training of manpower*. Similarly, internal consistency results and all constructs had a value greater than 0.7 (Chin, 2010).

Table2 Reliability and Internal Consistency Analysis

Constructs	Items	Factor Loading	Cronbach's Alpha
SP	SP0 SP1 SP2 SP3	0.762 0.729 0.821 0.803	0.81
PLC	PLC0 PLC1 PLC2 PLC3	0.791 0.944 0.710 0.855	0.74
STP	STP0 STP1 STP2	0.732 0.789 0.775	0.71
LTP	LTP0 LTP1 LTP2 LTP3 LTP4 LTP5 LTP6	0.816 0.854 0.767 0.799 0.763 0.759 0.778	0.73

3 items deleted from the construct of PLC

4. Analysis

Hypotheses 1& 2 tests the direct effects of sustainable practices *(SP)* on firm's short-term performance *(STP) and* long-term performance *(LTP)* respectively. Similarly, Hypotheses 3 & 4 investigates the mediating role of product life cycle stages *(PLC)* between *SP* and *STP* and between *SP* and *LTP* respectively. Four structural models are tested and a comparison is drawn between the models for managerial implications. Recommended values for *AVE* and *CV* are 0.5 and 0.7 respectively (Hair *et al*., 2010) and it can be observed that all constructs have values greater than the recommended minimum values. We can conclude that though the constructs are related in the framework, they are measuring different aspects in the relationship model.

Hypothesis 1 tests the relationship between *SP* and *STP* and the results indicate a relationship co-efficient of 0.2516** (significant at $p<0.001$, *t*-value = 17.35). Variance in *STP* is attributed to *SP* by 37.62%. Similarly, the results of hypothesis 2 suggest relationship co-efficient of 0.3342* (significant at $p<0.05$, *t*-value= 22.19) between *SP* and *LTP* and 40.14% variance in dependent variable *LTP* is explained by *SP*. The results of hypothesis 3 suggest a relationship co-efficient 0.6829** (significant at $p<0.001$, *t*-value= 16.94) between *SP* and *PLC* while the strength of relationship value is 0.5412* (significant at $p<0.05$, *t*-value 19.43) between *PLC* and *STP*. Lastly, hypothesis 4 tests the mediating role of *PLC* between *SP* and *LTP* and the results indicate a relationship co-efficient of 0.6829** (significant at $p<0.001$, t-value= 19.21) between *SP* & *PLC* while a relationship coefficient of 0.6186** (significant at $p<0.001$, t-value= 13.57) between *PLC* and *STP*. All of the result indices are reported in Table 3.

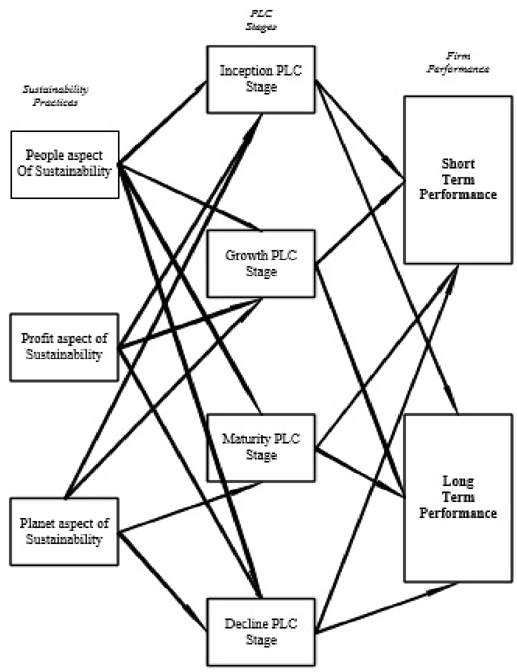
Table 3 Overall Results of the Study

Hyp.	Dependent Variable (DV)	Independent Variable (IV)	Direct effect	In-direct Effect	R^2, t-value	Status of Hypothesis
H1	Short term Performance	Sustainable Practices	0.2516**	----	0.3762, 17.35	Approved at $P<0.001$
H2	Long term Performance	Sustainable Practices	0.3342*	----	0.4014, 22.19	Approved at $P<0.05$
H3	Short term Performance	Product Life Cycle Stages	0.5412*	----	0.3242, 16.94	Approved at $P<0.05$
		Sustainable Practices	----	0.3695*	0.4937, 19.43	
H4	Long term Performance	Product Life Cycle Stages	0.6186**	----	0.4116, 1357	Approved at $P<0.05$
		Sustainable Practices	----	0.4224*	54.95%, 20.24	

5. Conclusion and Discussion

The relationship between sustainable practices and firm performance is mainly discussed in literature (Borland et al., 2016; Wiklund, 1999; Ortiz et al., 2016); however, little focus is provided to the role of life cycle stages in examining the relationship. An enterprise needs to align its sustainability efforts with different *PLC* stages dynamically to achieve more efficiency in the performance indices. For instance, as reported in Table 4, the total effect of sustainable practices on short term performance increases from *0.2516* (H_1) to *0.3695* (H_3) with an equivalent *11.75%* increase in R^2 value. It suggests that considering the mediating role of *PLC* stages in the framework enhances the relationship between *SP* and *STP* indices and also, the overall model becomes more robust. Similarly, including *PLC* in relationship framework of *SP* and *LTP* enhances the strength of relationship by *0.1* units while R^2 increases by *14.81%.* We can conclude that aligning the in-house sustainable practices *(People, Profit and Planet)* according to the life cycle stage of a product is rewarding not only in the short term *(returns and business growth)* but is also fruitful in long term accomplishments *(environmental footprints, reduction in emission, solid waste and social recognition).* Instead of considering product as a single unit and adopting sustainability protocols for the entire unit, it is suggested to consider the product by parts (4 *PLC* stages) and utilize the relevant sustainability approach in particular *PLC* stage in a dynamic and interactive manner. It can help an enterprise in multiple ways. *Firstly*, segregation of sustainable practices can help an enterprise in division of responsibilities according to a *PLC* stage. *Secondly*, demarcation between sustainable practices can help an enterprise to operate more efficiently, for example, more focus on profit in inception and growth stages and considering "people" aspect in maturity stage while "planet"/environment aspects in the decline stage. *Thirdly*, clustering bundles of sustainability practices according to *PLC* stages can provide an enterprise with imitable and tacit competitive edge in the market as it would be a start on new learning curve. *Lastly*, an enterprise can be more aware regarding the performance of its product and the consequences a product may cause during its service. Figure 1 contains a dynamic and interactive framework between *SP*, *PLC* stages and performance indices.

Figure 1 Interactive Framework between SP, PLC and Firm Performance



The purpose of sustainability is to use resources more efficiently in order to preserve them for the generations to come (Saltiel *el al*., 1994). A discussion is made on the importance of utilizing sustainability efforts according to *PLC* stages. Managers can utilize this framework by listing capabilities of production system and making clusters of them according to different *PLC* stages. The capabilities include but are not restricted to production efficiency for profit generation, human potential and environmental initiatives. As a demonstration, a follow-up content analysis of literature was performed to identify the most cited factors of sustainable practices. The list of factors was administered to the selected respondents and they were requested to examine the categorization of sustainable practices in different *PLC* stage. Literature based list of sustainable factors is provided in Appendix A. Exploratory Factor Analysis *(EFA)* was performed on the collected data to assign sustainable practices to different *PLC* stages (Kim *et al*., 2015). *EFA* was conducted using Principal Component Analysis *(PCA)* and orthogonal rotation was selected as different *PLC* stages are not correlated (Costello *et al*., 2005). The results of *EFA* are listed in Appendix B and categorization of sustainable practices according to life cycle stages is provided in Table 4.

Table 4 Assignment of Sustainable Practices to *PLC* Stages

Sustainable Practices	Adoption of Sustainable Practices in *PLC* Stages			
	Introduction Stage	Growth Stage	Maturity Stage	Decline Stage
1	✓			
2		✓		
3	✓			
4	✓			
5				✓
6			✓	
7			✓	
8				✓
9		✓		
10		✓		
11			✓	

12	✓			
13			✓	
14				✓
15		✓		
16			✓	
17	✓			
18				✓
19		✓		
20		✓		

Data for *EFA* analysis was collected from the same sample as the respondents were aware of the objectives and study design. A framework as a result of *EFA* analysis is provided in Figure 2 which clusters the sustainable practices according to *PLC* stages. Managers can use it as a decision-making tool to segregate the *SP* factors for utilizing their efforts optimally. For instance, the inception stage of *PLC* comprises of R&D, prototyping, raw material procurement, product development and finally, launching the product. As per the acquired results, relevant *SP* practices in this stage are optimal use of natural resources, eco-friendly design, eco-friendly process and green purchasing. Similarly, cluster of practices can be used for other *PLC* stages.

Figure 2 Decision Matrixes for Sustainable Practices Bundle

	Bundle of Sustainable Practices	
Product Life Cycle Stages	Inception Stage	*Sustainable use of natural resources, Eco-design, Green procurement, Eco-friendliness, Green purchasing*
	Growth Stage	*Adoption of the best available techniques, Training, Empowering personnel, Environmental regulation, Investment recovery, Profit margins*
	Maturity Stage	*Social welfare services, community awareness, pollution control, product life cycle analysis, cost of environmental friendliness*
	Decline Stage	*Environmental compliance, product responsibility, stewardship, cooperation with customers*

As a case example, the proposed framework was applied to two (2) enterprises for assessment of sustainable practices according to *PLC* stages. One of the selected enterprises was fabrication based while another was involved in bottle manufacturing practices. Archival data was analyzed for list of sustainable practices relevant to their context and a detailed analysis was performed according to the guidelines provided in Figure 2. The findings of case-based analysis are provided in Table 5.

Table 5 Application of proposed framework

Industry Type	List of Sustainable Practices (SP)	SP related to Inception PLC	SP related to Growth PLC	SP related to Maturity PLC	SP related to Decline PLC
Fabrication	Lean manufacturing, Total Quality Management, Research and Development, New learning curve, Energy consumption, Incentives for employees, Life cycle analysis, Health hazards, Community awareness, Profit driven production, Industrial safety, Environmental compliance, Product termination, Business leadership, Eco-friendly design, Solid waste reduction, Improving practices	Total Quality Management, Energy consumption, Industrial Safety, Eco-friendly design	Lean manufacturing, Research & development, New learning curve, Profit driven production	Incentives for employees, Life cycle analysis, Community awareness, Product termination, Improving practices	Health hazards, Environmental compliance, Business leadership, Solid waste reduction
Bottle Manufacturing	Green purchasing, Product recycling, Alternate techniques, Corporate social responsibility, Empowering personnel, Social welfare, Waste reduction, Stewardship, Feedback from clients, Product recovery, Improving practices, Pollution control, Quality standards, Benefits for workers, Sustainable process adoption	Green purchasing, Quality standards, Sustainable process adoption.	Alternate techniques, Empowering personnel, Improving practices	Corporate social responsibility, Social welfare, Product recovery, Pollution control, Benefits for workers.	Product recycling, Feedback from clients, Waste reduction, Stewardship.

6. Future Directions

The results reported in this study provide meaningful insights. In a resource constraint environment, optimal allocation of sustainable resources can enhance the productivity of an enterprise. The framework recommended in this study can be applied to an industrial context using a case study approach (Yin, 2009) to not only further generalize the findings but also to assist the practitioners in practical decision making. Another area of exploration is to consider the mediating effect of individual *PLC* stage in the relationship model of *SP* and firm performance. This practice can provide researchers with interactive insights such as the identification of sustainable efforts in different *PLC* stages for short-term and long-term performance. Practitioners can thus aim on sustainability actions needed for short term and long-term results, separately. A methodological recommendation for future research is to adopt longitudinal study design, unlike the current study which is cross-sectional. As discussed earlier, time span for the short-term accomplishments is 3-5 years while it is 7-10 years for long term goals. A longitudinal study conducted in multiple time spans can result in more robust and practical findings.

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Appendix

Exhibit A Factors of Sustainable Practices for Cluster Analysis

Sustainable Practice	Reference
Sustainable use of natural resources	Park et al., 2014
Adoption of the best available technique	Michelson et al., 2006
Eco-design	Bogue, 2007
Green procurement	Union, 2014
Environmental compliance	Taddeo et al., 2012
Social welfare services	Khodakarani et al., 2014
Community awareness	Shi et al., 2010
Product responsibility	Hussen, 2012
Training of employees	Robert, 2004
Empowering personnel	

Pollution control	Sanjay et al., 2005
Eco-friendliness	
Product life cycle analysis	
Stewardship	
Environmental regulations	Qinghua et al., 2004
Cost of environmental friendliness	
Green purchasing	
Cooperation with customers	Zhu et al., 2008
Investment recovery	
Profit margins.	

Appendix – B EFA Analysis of *PLC* Stages for *SP* Bundles

	Factors				
Item	Introduction	Growth	Maturity	Decline	Communality
1	0.784				0.766
3	0.725				0.740
4	0.692				0.705
12	0.633				0.652
17	0.587				0.601
2		0.891			0.872
9		0.864			0.861
10		0.778			0.824
15		0.742			0.761
19		0.656			0.687
20		0.618			0.634
6			0.824		0.812
7			0.802		0.764
11			0.719		0.717
13			0.644		0.680
16			0.637		0.639
5				0.818	0.802
8				0.634	0.735
14				0.602	0.669
18				0.576	0.591
Eigenvalue	12.45	6.82	4.37	2.08	
Total Variance Explained	61.86				

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